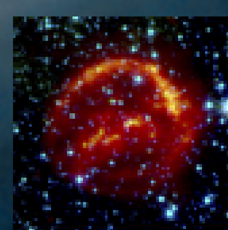
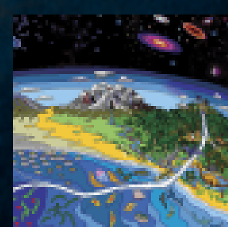
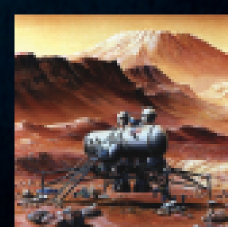
Space Science Division

Annual Report 2002–2003

NASA Ames Research Center







National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

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2002 – 2003 Annual Report

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Table of Contents

2002–03 Space Science Enterprise Overview

Scientists in NASA's Space Science Enterprise seek to answer fundamental questions about the origin and evolution of life and celestial objects (planets, planetary systems, stars, galaxies, etc.) in the universe. These questions are central to both the new NASA vision for the future: "To improve life here, To extend life to there, To find life beyond," and the new NASA mission: "To understand and protect our home planet, To explore the Universe and search for life, To inspire the next generation of explorers…, as only NASA can," as articulated by NASA Administrator Sean O'Keefe.

Ames is recognized as a world leader in Astrobiology, the study of life in the universe and the chemical and physical forces and adaptations that influence life's origin, evolution, and destiny. In pursuing our primary mission in Astrobiology, Ames performs pioneering basic research and technology development to further fundamental knowledge about the origin, evolution, and distribution of life within the context of cosmic processes. For example, research and technology development are currently conducted to:

- *Study the mechanisms of the origin, evolution, and distribution of life in the universe;*
- *Determine the abundance and distribution of the biogenic compounds that are conducive to the origin of life;*
- *Identify locations on bodies within our solar system where conditions conducive to life exist or have existed;*
- *Explore the other bodies (planets, comets, asteroids) of our solar system;*
- *Locate planets and planet-forming regions around other stars;*
- *Study extra-solar matter such as interstellar gas and dust.*

Research at ARC implements NASA and Space Science Enterprise goals through four elements dealing with Astrophysics, Planetary Systems, Exobiology, and Astrobiology Technology. Since a unifying theme for these elements is the origin and evolution of stars, planets, and life, the total research effort is a major thrust of the Space Science Enterprise's Astrobiology program. Astrophysics research addresses Enterprise goals and objectives that deal with understanding how the structure in the Universe emerged, the dynamical evolution of galaxies and stars, and the exchange of matter and energy among stars and the interstellar medium. Planetary Systems research addresses Enterprise goals and objectives that deal with understanding star formation, the evolution and distribution of volatile and organic material, the origin and distribution of planetary systems, rings, and primitive bodies, and planetary atmosphere evolution. Exobiology research addresses Enterprise goals and objectives that deal with understanding the origin, evolution, and distribution of life by conducting research on the cosmic history of biogenic compounds, prebiotic evolution, the early evolution of life, computational astrobiology, and extreme environments in which living organisms can exist. Astrobiology Technology supports fundamental research and the development of advanced technologies in astrobiology as they relate to the exploration of space and understanding of life in the universe.

This report highlights accomplishments in the four key research thrusts at Ames that support the goals and objectives of the Enterprise: Astrophysics, Planetary Systems, Exobiology, and Astrobiology Technology.

ASTROPHYSICS

As NASA's lead in airborne astronomy, scientists at Ames pioneered the field of astrophysics. Study topics range from star forming regions and processes to interstellar photochemistry to protoplanetary disks. Understanding cosmic processes—the evolution of the universe itself— is a vital part of the Origins initiative.

Ames' astronomers and astrophysicists utilize a wide variety of methods. Ground-based telescopes such as the Keck and Mount Lemmon Observatories, are regularly employed for observations of celestial objects and processes. Development continues on the Stratospheric Observatory for Infrared Astronomy (SOFIA), an infrared telescope to be carried aboard a Boeing 747 aircraft specially modified for the task. Space-based observations are also made through instruments such as the Hubble Space Telescope (HST) and other observatories and missions. Computer modeling and laboratory analogs of chemical processes enhance the observational astronomy performed.

Highlighted in this section of the report are a wide variety of accomplishments in astrophysics including:

- *Successful modeling of the observed color in icy planetary satellites using mixtures of ice and complex organic materials which sheds light on prebiotic organic chemical processes;*

- *Development of a cryogenic multiplexer for far infrared photoconductor detectors operating at moderate backgrounds for instruments for a new generation of large telescopes such as SOFIA;*

- *Contributions to the concept that Deuterium enrichment in meteorites indicates that organic species made in the ISM can survive the transition from a dense cloud through infall onto a planetary surface.*

PLANETARY SYSTEMS

Scientists in the Space Science Enterprise are interested in how and where in the universe planets form, and the geophysical, geochemical, and atmospheric processes that have occurred over the lifetime of a planet. Further, understanding the dynamics between planetary processes and the origin and evolution of life will help us understand the distribution of life in the universe.

Highlighted in this section of the report are a wide variety of accomplishments in planetary systems including:

- *New models which take into account the scatter of light from grainy surfaces shed new light on the composition of Saturn's rings;*

- *Theoretical models of particle —gas interactions in turbulent nebula flows helping to explain the abundance of Calcium-Aluminum-rich Inclusions (CAIs) in meteorites;*

- *The PASCAL Mars Scout Mission global network of long-lived landers to characterize the meteorology and climate of Mars;*

- *Theoretical research on star and planet formation conducted via consortium by the Center for Star Formation;*

- *The lessons of brown dwarf detection that can be applied to our search for extra solar planets;*

- *Novel techniques to detect and characterize large data sets from astronomical surveys identifying galaxy clusters without preset assumptions and conditions;*

- *Atacama desert in Chile, the best known Mars analog for scientist to perform soil chemistry and mineralogy studies in preparation for Mars exploration opportunities.*

EXOBIOLOGY

Ames' Exobiology Program is a key element of NASA's Astrobiology Initiative and Ames serves as NASA's lead center in exobiology. Research in exobiology at Ames ranges from studying the mechanisms of the origin of living systems, to the processes governing the evolution of life, and to the distribution of life on other planets. When coupled with Ames' pioneering research on the dynamics of galaxies, molecular gases and clouds, planetary systems, and the solar system, our study of life is facilitated by understanding the cosmic environment within which life originates and evolves.

Molecules of exobiological significance are ubiquitous in the universe. It is important to understand the sources and interactions of these building blocks and how living systems emerge from prebiotic molecular chaos.

Highlighted in this section of the report are a wide variety of accomplishments in exobiology including:

- *Biomarker analysis of ancient sediments associated with Cyanobacterial ecosystems might allow recognition of similar source organisms and environmental conditions on other worlds;*

- *Penning Ionization electron spectroscopy a new analytical technique that requires minimal flight resources while providing analyses of volatile complex chemical mixtures of atmospheres and surfaces of planetary bodies;*

- *The formation of protocells—membrane enclosed structures endowed with ubiquitous cellular functions—was a central step in evolution from inanimate to animate matter.*

ASTROBIOLOGY TECHNOLOGY

Ames' Astrobiology Technology Program supports fundamental research and the development of advanced technologies in astrobiology as they relate to the exploration of space and understanding life in the universe.

Highlighted in this section of the report are a wide variety of accomplishments in astrobiology including:

- *Atmospheric resources for exploration of Mars – has many of the ingredients needed to support human exploration missions;*

- *Nanotechnology – Technology on the scale of molecules, which holds the promise of creating devices smaller;*

- *The Vapor Phase Catalytic Ammonia Removal system technology represents the next generation in space flight water recovery system;*

The Division is organizationally divided into four Branches named according to the focus areas of the research conducted by the scientists in those Branches: Astrophysics, Planetary Systems, Exobiology, and Astrobiology Technology (see Figure 1).

In 2003, the Division employed 79 civil service personnel, approximately 50 of whom are Ph.D. scientists. This core permanent staff is augmented with approximately 125 non-civil servant scientists and technical support personnel who are resident in Division facilities through mechanisms such as grants, cooperative agreements, support contracts, fellowships, visiting scientist positions, and student internships.

It is common for visiting scientists to spend their summer research or sabbatical time in the Division's laboratories and facilities. Extensive ties are maintained with the academic community through collaborative research programs and also through the development of science curricular materials. The Space Science Division is dedicated to fostering greater interest in careers in the sciences and provides unique opportunities for training the next generation of scientists. Students at all levels—high school, undergraduate, graduate, and post-doctoral—represent a significant component of the Division's on-site research work force. In 2000, approximately 20 National Research Council Postdoctoral Fellows and 10 undergraduate students were resident in the Division. Division personnel also mentored students in the Astrobiology Academy, a competitive program for college undergraduates to participate in hands-on research projects here at Ames Research Center.

In the following section of the Annual Report, the research programs of each Branch are summarized. Within each area, several examples of research topics have been selected (from a total of approximately 130 tasks) for more detailed description. Following that section is a list of publications authorized by Division personnel with 2002 and 2003 publication dates. Finally, if a particular project is of interest, the personnel roster that begins on page 73 may be used to contact individual scientists.

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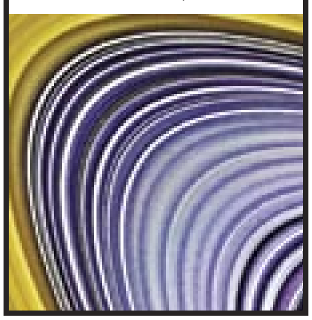

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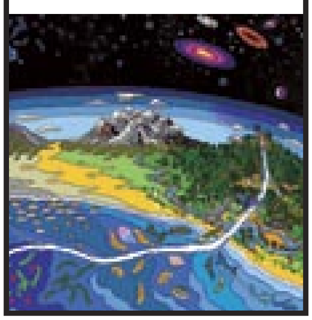

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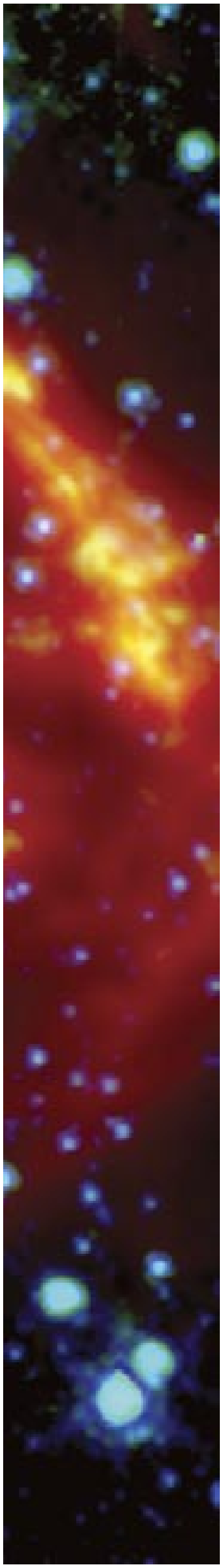
K. Bunn, Acting Asst. Chief

Figure 1.



Astrophysics Branch

Overview

Scientists in the Astrophysics Branch pursue a wide range of laboratory and observational astronomy research. The Branch is particularly interested in studying the physical and chemical properties of astronomical phenomena by observing their radiation at infrared (and ultraviolet) wavelengths, beyond the range of visible light.

Planets, stars, and the interstellar medium of the Milky Way and other galaxies are rich in infrared spectral features which provide clues to their origins, physics, chemistry, and evolution. Researchers use state-of-the-art laboratories, ground-based, airborne, and space-based observatories to conduct their research. Astrophysics Branch scientists, engineers, and technicians also play key roles in developing new NASA space and airborne missions and instruments such as SIRTF, NGST, and SOFIA. The primary products of the Astrophysics Branch are new observations of the universe and new instrumentation developed to make these observations.

DOUG HUDGINS

Acting Chief, Astrophysics Branch

FITTING REFLECTION NEBULA SPECTRA WITH LABORATORY PAH DATA

Jesse Bregman and Pasquale Temi

The mid-infrared spectra of reflection nebulae are dominated by emission from polycyclic aromatic hydrocarbon (PAH) molecules. These molecules emit radiation in a number of discreet bands, and we can identify which molecules are present in reflection nebulae by matching the observed bands with those of specific PAH molecules measured in the laboratory. However, the astronomical spectra are not from a single PAH molecule, but rather a mixture of both electrically charged and neutral molecules. The charge state of the PAHs depends on the density of the nebular gas and the intensity of the incident ultraviolet (UV) radiation. Since the UV intensity decreases with increasing distance from the star that illuminates the nebulae, it is likely that the charge state of the PAHs changes from being more highly ionized near the star to more neutral at increasing distances from the star.

We have used spatial-spectral image cubes from the Infrared Space Observatory (ISO) to study how the spectrum of a reflection nebula changes with distance from its exciting star, and whether these changes can be explained by a change in the fractional ionization of PAHs. Our procedure is to first divide the nebula into regions that show similar spectra. For the reflection nebula vdB133, this procedure gave about 5 distinct regions, each with a somewhat different average spectrum. The main spectral difference between these regions was the relative strength of the emission bands in the 6-8 µm region relative to those in the 10-14 µm region. Each of the spectra were then fitted with a mixture of laboratory spectra of PAHs taken from the Ames Astrochemistry Spectral data base. Figure 1 shows the fit (dashed line and squares) to one of the spectral classes in vdB133 (solid line and triangles). A non-negative least squares fitting routine is used to fit the data with a linear combination of up to 36 laboratory spectra. In this example, the routine only used 15 of the spectra, weighting them so that when added together, they would provide the closest fit possible to the vdB133 spectrum.

Figure 2 shows the weights that the fitting routine calculated for three different spectral classes in vdB133. The points with class 5 spectra are closest to the star followed by class 2, while class 3 points are farthest

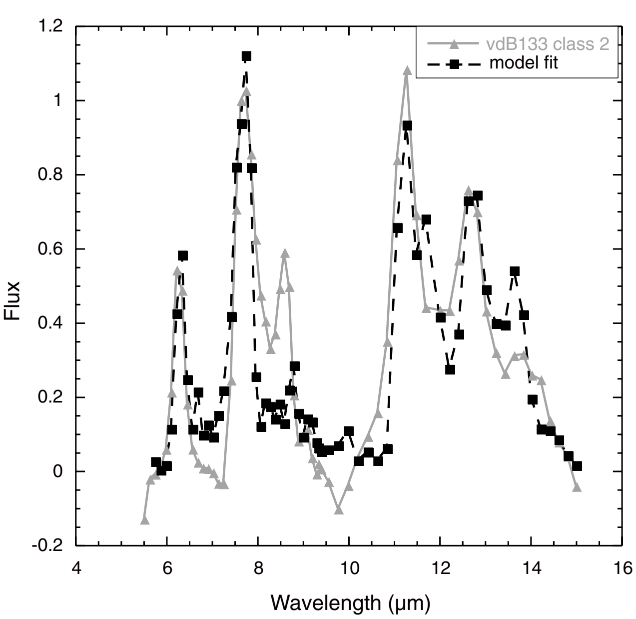


Figure 1. The average spectrum of one region in the reflection nebula vdB133 is shown as the solid line and triangles overlaid with a spectral fit (dashed line, squares) using a linear combination of spectra from the Ames Astrochemistry Lab data base.

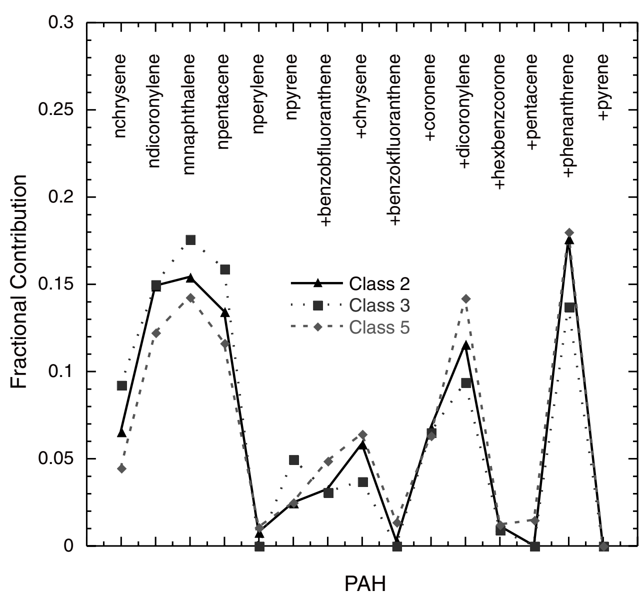


Figure 2. The contribution to the total intensity of the spectrum of 15 different neutral (designated n) and ionized (+) PAHs is shown for three different regions in vdB133. There is a progression of decreasing amounts of ionized PAHs relative to neutral PAHs as the UV radiation intensity experienced by the regions decreases.

from the star. The spectral fits show a progression of decreasing amounts of ionized species and greater amounts of neutral species progressing from class 5 to 2 to 3. Whether the individual PAHs that are used for the fit actually are present in the reflection nebulae is not known, although if the spectral changes can be explained by simply trading ionized for neutral species of the same molecule, then we might have evidence for that PAH being present. Further study using spectra of larger PAH molecules and only spectra of the same neutral and ionized species rather than the entire data base will perhaps lead to identification of individual PAHs.

ROTATION PROPERTIES OF SUN-LIKE PROTOSTARS

Thomas Greene

We can understand better how the Sun and Earth formed by studying very young stars in relatively nearby cosmic clouds of gas and dust where stars are forming now. Ames is involved in conducting astronomical observations of such young protostars using a powerful infrared spectrograph on the Keck Telescope in Hawaii. These observations reveal the physical properties of the youngest stars ever observed, and they show how these stars are interacting with the disks of material around them which will eventually form planets.

The temperatures, sizes, and rotation speeds of stars can be measured by observing them with spectrographs on large telescopes. Spectrographs disperse starlight into its constituent spectrum (colors), revealing telltale features which are produced by chemical elements in stellar atmospheres. Different features appear at different temperatures and pressures, and any rotation by the star broadens theses features via the Doppler effect. Putting this together allows precise measurement of stellar temperatures, sizes, and rotation speeds.

Until now it has been impossible to observe protostars – the youngest stars (less than 100,000 years old) which are still actively accreting their mass – with spectroscopy. This is because protostars form in very heavily obscured cosmic clouds of dust and gas where visible light cannot penetrate. However, protostars often emit large amounts of infrared radiation (wavelengths longer than visible light). Spectrographs which are sensitive to infrared light have recently been developed, and Ames personnel have been such instruments on the world's largest telescopes to measure the physical properties of protostars.

Early results from these studies indicate that protostars have temperatures and radii (sizes) which are very similar to somewhat older young stars (about 1,000,000 years old) which have stopped building up their masses. However, protostars are rotating about 2 –3 times as fast as the non-accreting young stars. This comes about for two reasons. First, a protostar is surrounded by a flattened disk of dust and gas which flow onto the central protostar, building up its mass. This material rotates faster and faster as it spirals through the disk, conserving its angular momentum just as an ice skater does when she brings in her arms and spins up. Therefore this accreting material spins up the protostar also. However (and secondly), the protostar is also coupled to its disk by strong magnetic fields which originate in the protostar (similar to the Sun in sunspot regions). This field couples the protostar to a region of its disk which is rotating rapidly. Older young stars (which are no longer accreting much matter) also have magnetic fields, but they are coupled to farther, more slowly rotating regions in their disks. The coupling distance and the resultant rotation speed are determined by the magnetic field strength and the amount of mass which is flowing from the disk onto the protostar. This is shown in Figure 1.

The rotation speeds of young stars and their disks are regulated by their magnetic strengths and the rate at which matter stops flowing onto the central stars. It is important to study this further because planets form in disks around stars, and the distribution of matter in disks is influenced by these processes.

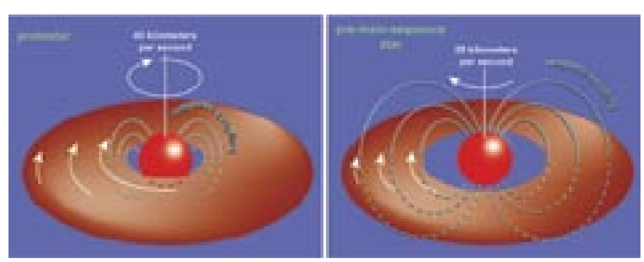


Figure 1. A schematic illustration which shows how stars are coupled to their disks for fast rotating protostars (left) and slower rotating young stars which have stopped accreting mass (right).

OPTICAL SPECTROSCOPY OF COSMIC / INTERSTELLAR ICES

Murthy Gudipati and Lou Allamandola

Water-rich ices, which harbor a wide variety of organic and inorganic species, are common throughout the Solar System and interstellar molecular clouds, the birthplace of stars and planets. The recent interest in searching for signs of life in water rich habitable bodies in the Solar System such as Europa and addressing questions concerning the abundance of water on Mars by the Mars Odyssey Mission exemplify the importance of water-rich ices in the cosmos. Chemical reactions induced within these cosmic ices by high-energy photons and cosmic rays play a vital role in the chemical evolution of these icy objects and their coloration. From the astrobiological perspective, complex prebiotic organic molecules are generated, including amino acids; amphiphillic, membrane forming molecules; and functionalized polycyclic aromatic hydrocarbons (PAHs).

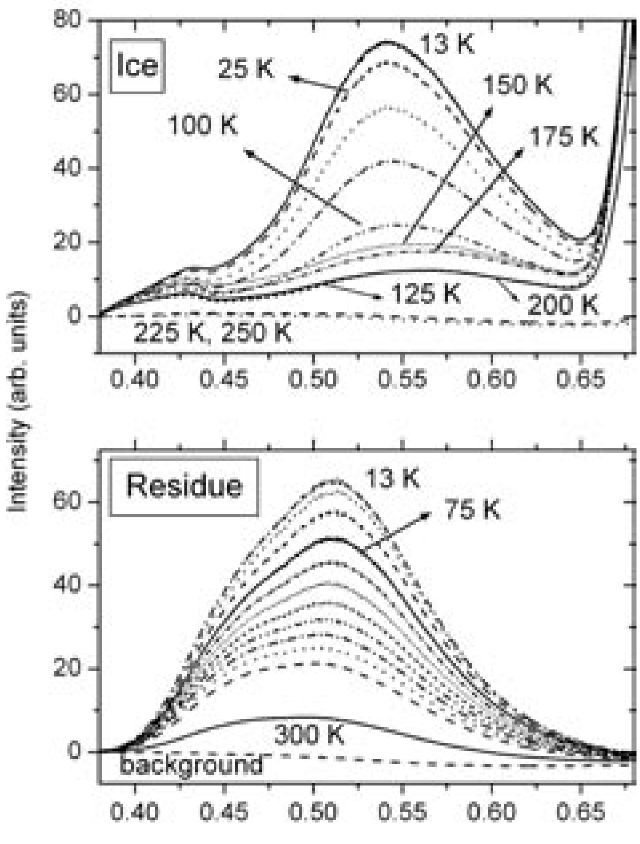


Figure 1: Temperature dependent luminescence from VUV-processed cosmic ice (top) and its residue (bottom) when excited with 380 nm light. The luminescence intensity increases with decreasing temperature.

Luminescence of cosmic ices: Due to the fact that cosmic ices are home to such important prebiotic chemistry, it is important to understand the primary physical and chemical processes that occur in these ices when they are exposed to high energy photons and cosmic rays. Our laboratory studies show that, upon vacuum ultraviolet (VUV) photolysis, transparent cosmic ice analogs containing H_2O, CH_3OH, CO, and NH_3 become strongly colored and exhibit green luminescence. This luminescence originates in the complex non-volatile organic molecules that are produced by the VUV photons and, upon warm-up to room temperature, remain even after the simple parent ice molecules have evaporated (shown in Figure 1). The ultraviolet-pumped green emission is an order of magnitude more intense at cryogenic temperatures (15 K) than at room temperature. Thus, very cold icy cosmic objects that receive considerable amount of high energy photons or cosmic rays should show this green emission. The types of objects which can exhibit this induced emission include comets, planets and their satellites, outer Solar System objects and interstellar ices. As an example, these studies have been used to reinterpret the reflection spectrum of the leading side of Iapetus, a moon of Saturn as follows.

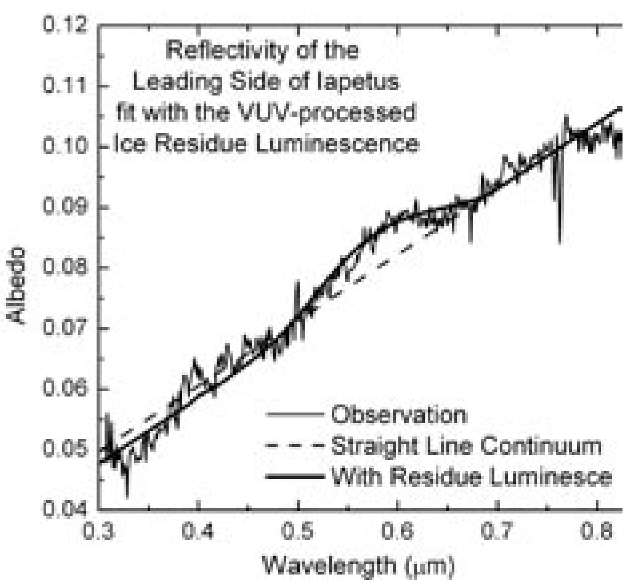


Figure 2: Reflection spectrum of the leading side of Iapetus (jagged solid line), fitted with a straight baseline (dashed line) to represent overall slope of the data. Addition of the ultraviolet pumped emission of the cosmic ice residue to the straight line results in a nice fit with the observed albedo (thick solid line).

It has been long known that Iapetus exhibits an extreme dichotomy in the amount of sunlight reflected from it's leading and trailing hemisphere. The dark, leading hemisphere, "reflects" less than 10% of the incident sunlight (albedo < 10%) while the bright, trailing hemisphere has an apparent enhanced "reflection" of ~50% (albedo ~50%). At visual and near-infrared wavelengths (~0.3–1.0 mm) the spectrum of the leading hemisphere is distinctly red with a weak and broad reflectance minimum near 0.67 mm. The broad feature centered near 0.6 mm might arise from luminescence of materials similar to the non-volatile residues mentioned above. Addition of the emission spectrum of cosmic ice residue, appropriately scaled, to the straight baseline representing the continuum color of Iapetus resulted in surprisingly good fit with the observed albedo, as shown in Figure 2.

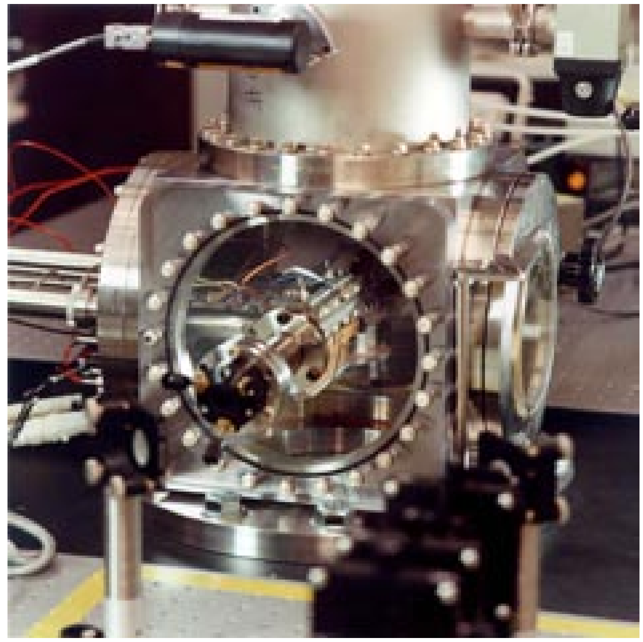


Figure 1: The figure shows Ames Interstellar Simulation Chamber (ISC). The physical conditions maintained inside the chamber approach interstellar conditions.

FROM GROUND TO SPACE - NEW RESULTS WITH AMES INTERSTELLAR SIMULATION CHAMBER: CAVITY RING DOWN SPECTROSCOPY OF INTERSTELLAR ANALOGS

Farid Salama, Ludovic Biennier, Jerome Remy, Robert Walker, Manish Gupta, and Anthony O'Keefe

New results have been obtained using Ames Interstellar Simulation Chamber (ISC) allowing for the first time to measure the spectral signature of large interstellar carbon molecules analogs and to accurately model the "cold" plasma that is generated in this unique astrophysical environment. The ISC facility has been developed to directly simulate gaseous molecules and ions at the low temperature and pressure conditions of interstellar space. This laboratory facility -that is unique within NASA- combines the techniques of Supersonic Free-Jet Expansion with the techniques of Cavity Ring Down Spectroscopy. The principle objective is to determine the spectroscopic properties of large interstellar aromatic molecules and ions under controlled conditions that precisely mimic interstellar conditions. The aim of this research is to provide quantitative information to analyze astronomical spectra in support of NASA's Space Science and Astrobiology missions, including data taken with the Hubble Space Telescope.

Understanding the origin, physical properties, and distribution of the most complex organic compounds in the universe is a central goal of Astrophysics and Astrobiology. To achieve this requires generating and maintaining large carbon-containing molecules and ions under interstellar-like conditions while simultaneously measuring their spectra under these conditions (i.e., in the gas phase at very low densities and at very low temperature). This has been accomplished by combining four advanced techniques: free supersonic jet expansion, low-temperature plasma formation and the ultrasensitive techniques of cavity ring down spectroscopy and multiplex integrated cavity output spectroscopy (ICOS). The ISC combines a pulsed-discharge, supersonic slit jet source mounted in a high-flow vacuum chamber with a ringdown cavity (see Figure 1). A beam of carrier gas (argon) seeded with polycyclic aromatic hydrocarbon molecules (PAHs) is expanded in the gas phase into the cavity ring down chamber. When the expanding beam is exposed to a high-voltage ionizing electronic discharge, a "cold" plasma is generated leading to the formation of positively charged ions that are characterized by very low, interstellar-like, rotational and vibrational temperatures (temperatures of the order of 10 and 100 K respectively are achieved this way). We have characterized the cold plasma as a restricted glow discharge. Recording the cavity ring down signal is a direct measurement of the absolute absorption by the seeding molecules and ions. Varying the gas pressure and the discharge voltage in the chamber also leads to the formation of nano-sized carbon particles and offers a highly sensitive way to trace the formation process of solid particles out of their molecular precursors (or "building blocks"). The results are illustrated in Figure 2 that shows the ICOS spectrum of the PAH acenaphthene ion (C12H10+). This unique experimental facility has been developed in collaboration with Los Gatos Research through a Small Business Innovative Research (SBIR) contract.

The data shown in Figure 2 can now be used to analyze the spectral signatures seen in astronomical spectra and to derive key information on the nature of the interstellar medium. For example, the absorption band of the PAH ion C12H10+ shown in Figure 2 can be directly compared to the absorption spectrum of the diffuse interstellar bands (DIBs). These bands that contribute to the global interstellar extinction were discovered eighty years ago and remain an enigma to this day.

For the first time, the absorption spectrum of large organic molecules and ions can be measured up to nanometer-sized species (nanoparticles) under conditions that mimic entirely the interstellar conditions.

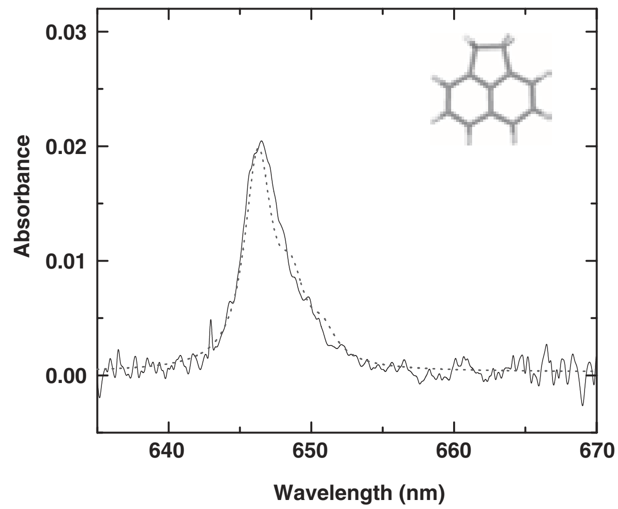
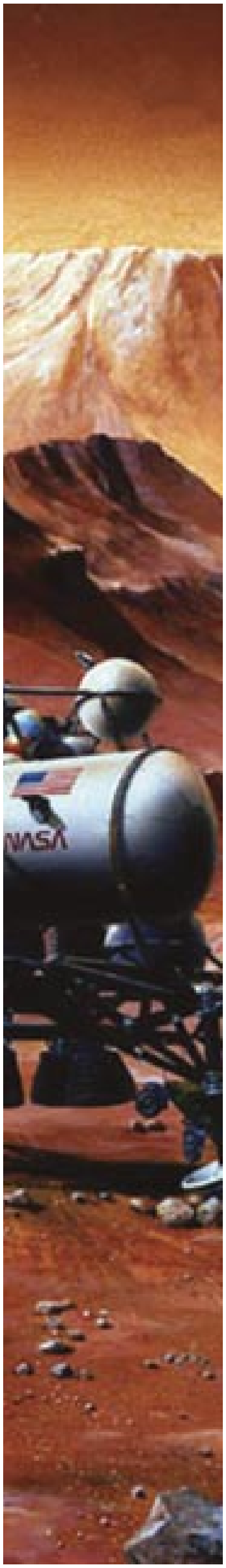


Figure 2: The multiplex ICOS absorption spectrum of the acenaphthene cation ($C_{12}H_{10}+$) measured for the first time in the gas phase under simulated interstellar space conditions. The spectrum is obtained when an argon free jet expansion seeded with acenaphthene is exposed to a high-voltage discharge.



Astrobiology Technology Branch

Overview

The Astrobiology Technology Branch supports fundamental research and the development of advanced technologies in astrobiology as they relate to the exploration of space and understanding life in the universe. Current branch efforts encompass research and technology development for advanced life support, utilization of planetary resources, and astrobiology. Advanced Life Support focused research is directed primarily at physicochemical processes for use in regenerative life support systems required for future human missions and includes atmosphere revitalization, water recovery, waste processing/ resource recovery, and systems modeling, analysis and controls associated with integrated subsystems operation. In-Situ Resource Utilization (ISRU) technologies will become increasingly important on every Mars lander between 2003 and a human mission to Mars. The branch focus is on the development of technologies for Mars atmosphere acquisition, buffer gas production, and CO_2 compression. Research and technology development for astrobiology includes understanding the physical and chemical limits to which life has adapted on Earth, the molecular adaptations that have allowed living systems to inhabit extreme environments, and the application of this knowledge to biotechnology, nanotechnology, and planetary protection. Researchers in the branch also develop flight experiments and associated hardware for shuttle, ISS, and unmanned NASA missions.

Mark H. Kliss

Branch Chief, Astrobiology Technology Branch

CLEAN INCINERATION FOR SPACE MISSIONS

John W. Fisher and Suresh Pisharody

One of the research objectives at NASA Ames Research Center is the development of solid waste processing technologies for long duration exploration missions. A major part of this research effort entails the recovery of resources from life support wastes, such as the recovery of carbon dioxide and water from waste biomass via incineration. Carbon dioxide and water can be used as part of a regenerative life support system to grow plants for food. One of the central problems associated with incineration is the production of undesirable or toxic byproducts of combustion. Ames has developed an incineration flue gas cleanup system that allows use of the carbon dioxide in a plant growth system and that allows release of the remainder of the clean flue gas back to the crew cabin.

As space missions increase in duration, there will be an increased need to transition from life support systems using stored life support materials to life support systems using recycled life support materials. For instance, for short duration missions food can be stored, however, for missions lasting several years, food will need to be provided from a number of possible sources. One viable source is a plant growth chamber. Growing food in space will require recycling waste materials for the raw materials necessary for plant growth: carbon dioxide, water, and nutrients. Incineration offers a method of converting waste materials such as inedible biomass (the part of a plant that can not be eaten) back into carbon dioxide, water, and nutrients (ash).

The process of combustion of biomass in an incinerator operates in a way similar to the combustion of wood in a fireplace—the biomass is almost completely oxidized to gaseous carbon dioxide and water vapor, and only a small residue of inorganic substances (ash) is left. Even in the best of combustors, however, some unoxidized material remains, and toxic byproducts and/or contaminants such as nitrogen and sulfur oxides are formed.

In recent years, research at Ames has focused on developing methods to eliminate the undesirable combustion byproducts. One approach has been to use reductive catalytic systems to convert the nitrogen and sulfur oxides to nitrogen and elemental sulfur, innocuous materials at room temperature. Oxidative catalysts can then oxidize the remaining hydrocarbon contaminants to very low levels. In collaboration with outside university and corporate organizations, an integrated incineration system has been developed and tested that utilizes a fluidized-bed combustor followed by a catalytic cleanup system. In the past year, this system has demonstrated the ability to burn inedible biomass and produce a very clean exit flue gas. The concentration of contaminants in the gas exiting the incinerator is generally less than a few parts per million. Except for the carbon dioxide, which is toxic to humans at high concentrations, the exit stream from the incinerator is able to meet the Space Maximum Allowable Contaminant (SMAC) standards for clean air in a spacecraft.

A second research effort at Ames is investigating the use of waste material to prepare the flue gas cleanup system. A pyrolytic process converts inedible biomass to char, and the char is then converted to activated carbon. The activated carbon is used to remove contaminants such as nitrogen oxide and sulfur dioxide from the incinerator flue gas by adsorption followed by chemical reaction with the carbon. The contaminants are thus converted to innocuous nitrogen gas and elemental sulfur. In the past year, the process of producing activated carbon from wheat straw has been demonstrated, and the activated carbon produced from wheat straw has been used to reduce the concentration of nitrogen oxides in incinerator flue gas from 300 ppm (parts per million) to less than 1 ppm. This meets the SMAC limits within the crew cabin.

With the development of energy efficient, optimized incineration and flue gas cleanup systems, NASA will have the technology necessary to “close the loop” on carbon. Ultimately, carbon will move within the system from plant to person and/or incinerator and back to the plant without ever becoming a stored waste, achieving a significant milestone in the development of advanced life support systems which approach self-sufficiency.

ATMOSPHERIC RESOURCES FOR EXPLORATION OF MARS

John Finn, Dave Affleck, Lila Mulloth

The atmosphere of Mars has many of the ingredients needed to support human exploration missions. It can be "mined" and processed to produce oxygen and buffer gas for breathing (used to dilute oxygen). With lightweight hydrogen transported from Earth, or using water found in local deposits as a hydrogen source, storable methane rocket fuel can also be produced. The use of local materials, called ISRU (for in situ resource utilization), is an essential strategy for a long-term human presence on Mars from the standpoints of self-sufficiency, safety, and cost. It is a key cost-reduction element of NASA's Strategic Plan.

The atmosphere of Mars is roughly 95% carbon dioxide, 3% nitrogen, and 2% argon. There are also trace amounts of other gases. Carbon dioxide is the resource for oxygen and also provides the carbon that can be used in methane production. The production of these gases will likely dominate any early Mars manufacturing plant because of the quantity of materials needed to return samples or humans to orbit or to Earth. However, it is important to recognize that buffer gas also represents a considerable launch mass, estimated on the order of two to three tons for a human mission (mainly due to airlock activity). With the proper selection of gas acquisition and processing technology, a more optimal ISRU plant can be designed that will provide all these resources with minimal mass and power consumption.

For example, carbon dioxide must be acquired from the Mars atmosphere, purified, and pressurized in order to be useful in a propellant production plant. Buffer gas is a potential by-product of the purification process. NASA Ames developed a process whereby the small amount of nitrogen and argon present in the atmosphere are efficiently separated from the carbon dioxide during an adsorption compression process (see figure 1). Carbon dioxide adsorbs in the first bed, while nitrogen and argon pass through and are collected in a separate adsorption bed. When the first bed is heated, carbon dioxide is driven off at elevated pressure. Similarly, the nitrogen and argon are driven off at pressure when the second bed is heated. Such temperature-swing adsorption compression and separation processes are highly efficient and are expected to work well on the cold Martian surface. Being virtually solid-state, they do not suffer the wear and reliability problems associated with operating mechanical pumps in that hostile environment.

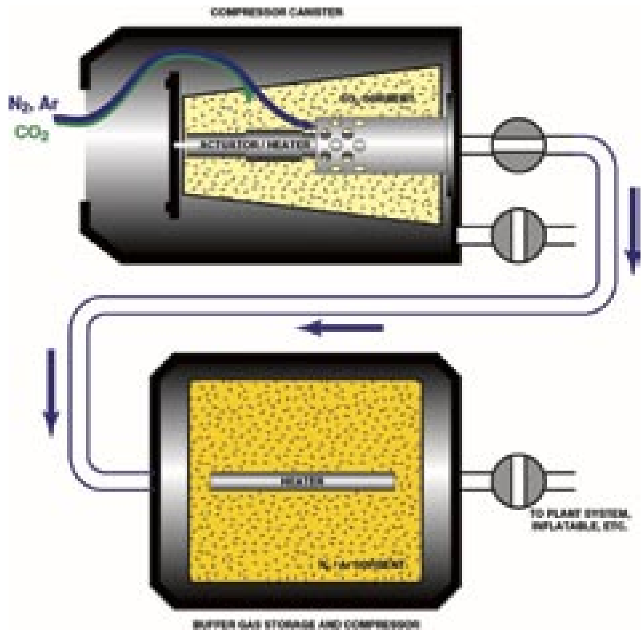


Figure 1. Flow diagram of an adsorption-based CO_2 compression and N_2/Ar separation device for the Mars atmosphere.

ROTATING-DISK ANALYTICAL SYSTEM (R-DAS)

Michael Flynn and Bruce Borchers

One of the main limitations in increasing the scientific return from fundamental biology and life sciences experiments onboard the International Space Station (ISS) is the inability to conduct a variety of biological and analytical assays in flight. The Rotating-Disk Analytical System (R-DAS) is an automated analytical/cell culture laboratory that has been developed as a biotech and chemical analytical instrument for use on ISS and other space flight platforms. R-DAS uses a microfluidics rotating disk and predetermined spinning profiles to accomplish complex fluid management tasks. Analysis is accomplished through the use of a custom optical imaging system. The instrument can conduct

Figure 1. R-DAS Instrument

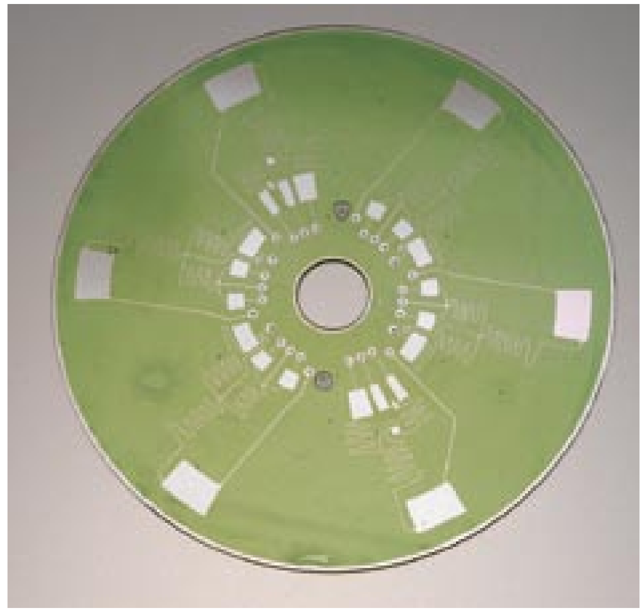


Figure 2. R-DAS Microfluidic Disk.

a wide range of protocols on orbit with onboard 1-g and micro-g controls without the need for the ISS centrifuge.

The system has a variety of unique design features such as automated microgravity environment assays and optical detection schemes which support natural and induced fluorescence. It is capable of conducting calorimetric, spectral, and image analysis. It will provide in-flight 1-g control studies without the need for the ISS centrifuge. It uses sealed and disposable sample disks which are pre-configured with all necessary reagents. The use of centrifugal force to control fluid flow minimizes acceleration velocities and shear forces and creates an environment which is insensitive to two-phase microgravity flow restrictions thereby simplifying sample preparation and introduction procedures.

The system is designed to fit into a double mid-deck locker (1/4 Space Station rack). It is designed to remain on orbit with only the disks being transported back and forth to orbit. A disk storage/holding system will be provided in order to allow for multiple disks processing. Operational protocols can be written on CD disks and experimental results can be re-written on the CD disks.

Ames Research Center has recently completed a rapid system prototype development effort. This six-month effort has resulted in the development of the prototype R-DAS system. The prototype is shown in Figure 1. This system is fully automated and uses a single microfluidic disk (single assay) with six parallel flow paths. The disk is shown in Figure 2. A florescent microscope is incorporated into the design in order to image samples and provide complete image analysis. The system is portable, having dimensions of only 8 in. x 20 in. x 20 in. The prototype was completed on January 1, 2002, and is currently being validated against standard laboratory protocols. In order to provide a first demonstration assay, a unique microfluidic disk was fabricated using the Molecular Probes Live/Dead stain assay.

Live/Dead Bacterial Viability Kit stains are based on the use of SYTO 9 green fluorescent nucleic acid stain and the propidium iodide red-fluorescent stain. Live/Dead kits are also available for animal cells and yeast assays, both of which will work in the existing R-DAS disk system.

Initial test results from the prototype system Live/Dead assay are encouraging. In addition, the system design is such that R-DAS is readily adaptable to a variety of other assays/disks being evaluated. With further development, R-DAS promises to usher in previously unavailable biological laboratory analysis capability onboard ISS and other future space flight platforms.

PROTEIN NANOTECHNOLOGY

Jonathan Trent, Andrew McMillan, Chad Paavola

In support of NASA's efforts to improve mission success, there is a growing need for the development of smaller, stronger and "smarter" scientific probes compatible with space exploration. The necessary breakthroughs in this area may well be achieved in the revolutionary field of nanotechnology. This is technology on the scale of molecules, which holds the promise of creating devices smaller and more efficient than anything currently available. Although a great deal of exciting research is developing around carbon nanotubes-based nanotechnology, investigators at NASA Ames Research Center are also exploring biologically inspired nanotechnology.

The biological "unit," the living cell, may be considered the ultimate nano-scale device. Cells, which are constructed of nano-scale components, are extremely sensitive, highly efficient environmental sensors capable of rapid self-assembly, flawless self-repair, and adaptive self-improvement; not to mention their potential for nearly unlimited self-replicate. Ames is focusing on a major component of all cells (proteins) that are capable of self-assembling into highly ordered structures. A protein known as HSP60 is currently being studied that spontaneously forms nano-scale ring structures (Figure 1A, end view; B, side view), which can be induced to form chains (Figure 1C) or filaments (Figure 1D).

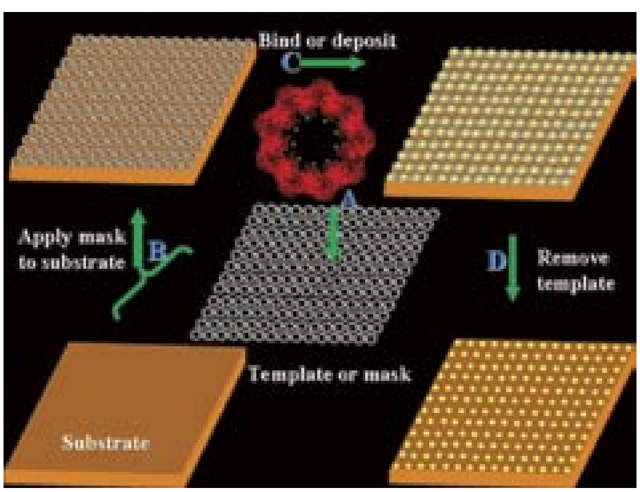


Figure 1: Protein rings (A end view, and B side view), chains of rings (C), and bundles of chains (D) that can be used in nanotechnology. Two-dimensional crystals (E) of mutated rings used for metal array formation.

By using thermostable HSP60s, highly efficient methods have been developed for purifying large quantities of these proteins and by using the "tools" of molecular biology , their composition and structure-forming capabilities are being currently modified.

Recently, progress has been made in evolving the HSP60 into a structural subunit that can be manipulated in such a way as to utilize it for the formation of ordered arrays. Ordered arrays of metals are of interest in the semiconductor engineering community for the fabrication of devices that can be addressed and further assembled into logical circuits. To this end, a portion of the wild-type HSP60 subunit identified as contributing to the formation of filaments, or end-on structures, has been removed at the genetic level. The removal of this region of DNA directs the expression of a protein incapable of organizing into filaments; however, it possesses the ability to crystallize in two dimensions in a highly ordered hexagonally packed array (Figure 1E). This ordered array is being used to direct deposition of metals

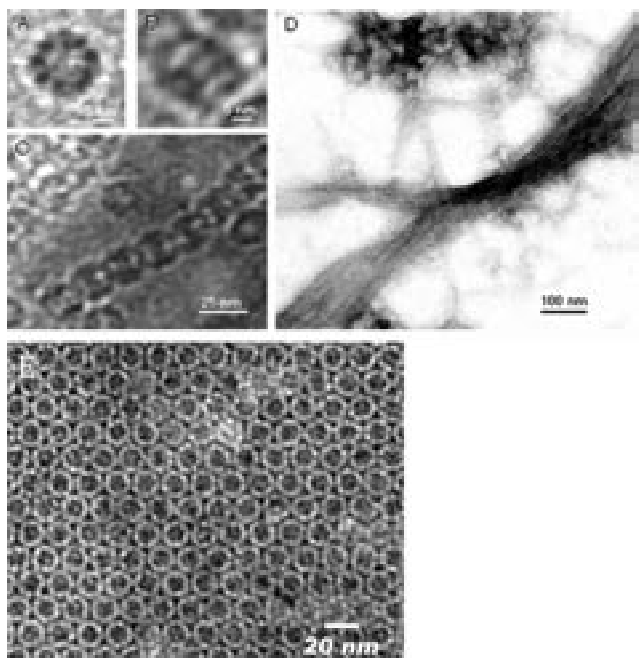


Figure 2: Mutant forms of HSP60 possess genetically engineered chemical reactivity at specific sites on the rings (A, green dots). These rings are crystallized (A) in two dimensions forming a highly ordered template. The template is applied to the surface of a substrate (B), and metals are bound that specifically attach to defined sites throughout the crystal (C). Finally, the template is removed (D), and the ordered array remains bound to the substrate.

by templating. This process takes advantage of both the propensity of the modified subunit to self-assemble into a highly ordered array and the ability to site-specifically functionalize the protein. Using this approach, specificity for metals can be engineered into the protein that will subsequently localize the metals at defined intervals along the protein and hence into an ordered array (Figure 2). A simple removal of the protein leaves the ordered array of metal on the substrate with nanometer scale feature resolution.

PROTEINS AS TOOLS FOR BIONANOTECHNOLOGY

Jonathan Trent, Andrew McMillan, and Chad Paavola

NASA's efforts to optimize space exploration are enhanced by the development of smaller and more powerful sensors and information storage and processing devices. These devices, which depend on the controlled organization of materials into addressable arrays, are currently being fabricated primarily by lithographic techniques. While these techniques have been refined to create devices on the micron scale, there are compelling reasons to produce nanoscale devices. In addition to the increased packing density, on the nanoscale there are quantum effects that rely on the behavior of single electrons. These quantum effects open new horizons in the design and development of sensors and electronic devices that will have a significant impact on the performance of future NASA space probes.

Controlled assembly of materials on the nanometer scale, however, presents a formidable problem. It is beyond the theoretical and practical limits of conventional lithographic patterning processes and while alternate techniques, such as X-ray and ion beam lithography have the resolution to reach the nano-scale, they are currently prohibitively expensive. We are developing a radical new technique for patterning materials on the nanoscale using proteins.

Proteins are self-assembling biomolecules that naturally form highly ordered structures and that can be modified and manipulated by genetic engineering. Genetic engineering transforms natural proteins into "nano-agents" that are capable of recognizing, binding, and ordering nanoscale materials.

NASA Ames has demonstrated the feasibility of using proteins as nano-agents with a class of proteins called HSP60s. These proteins naturally associate to form rings 17 nanometers in diameter called chaperonins. Chaperonins can be induced to form higher order structures such as chains or two- and three- dimensional crystals. By genetically engineering HSP60s to bind metal or semiconductor quantum dots, chaperonins can create useful nanoscale devices such as wires, waveguides, and quantum dot arrays. Two-dimensional crystals of chaperonins have been used to produce two-dimensional arrays of quantum dots as shown in Figure 1 adapted from a Nature Materials article. The properties of these arrays and the construction of other structures using chaperonins are now under investigation. The knowledge gained from these investigations combined with new techniques in genetic engineering represent a formidable tool for nanotechnology. NASA is helping to explore these new frontiers that will ultimately play a key role in future NASA missions.

EXPLOITING THE PHYSICO-CHEMICAL PROPERTIES OF SINGLE-WALLED CARBON NANOTUBES FOR ADVANCED LIFE SUPPORT APPLICATIONS

John Fisher, Martin Cinke, K. Wignarajah, Jing Li, Suresh Pisharody, Harry Partridge

NASA Ames is investigating the potential applications of single-walled carbon nanotubes for trace contamination control in future manned space missions. A number of solid waste treatment technologies are under investigation for the function of resource recovery during long duration manned missions. Inherent to many of these candidate technologies (for example, incineration) is the production of undesirable by-products such as nitrogen oxides, carbon monoxide, trace hydrocarbons, and sulfur dioxide. The success of waste processing resource recovery technologies thus depends on the ability of gas clean-up systems to efficiently remove these contaminants from regenerative life support systems with minimal use of expendables. Existing industrial processes employed to reduce byproducts from effluent gases typically require the use of expendable materials such as ammonia, carbon monoxide or hydrocarbons in the presence of a catalyst.

Single-walled carbon nanotubes (SWCNT) are excellent candidates as catalysts and catalyst support materials for trace contaminant control. They possess highly selective adsorptive properties and high surface areas. Based on theoretical predictions with proper control of tube spacing and tube diameter, Brunauer-Emmett-Teller (BET) surface areas approaching 3200 squared meters per gram are possible for the bulk material (opened tubes), which includes a significant contribution from the interior pores (endohedral surface) and channels approaching 1500 squared meters per gram.

To date, carbon nanotubes have been shown to be very effective catalyst supports for the conversion of nitrogen oxides to nitrogen and oxygen without the need for any exogenous consumables such as carbon monoxide and ammonia. Catalyst impregnation of single-walled nanotubes is necessary to enhance the conversion efficiency of the trace contaminants and to reduce the conversion temperature. Rhodium impregnation and characterization of SWCNT's has been studied in the past year. Impregnation of the single-walled nanotubes with metals such as Palladium, Platinum, Silver, Ruthenium and Niobium are being tested for removal of spacecraft cabin air trace contaminants.

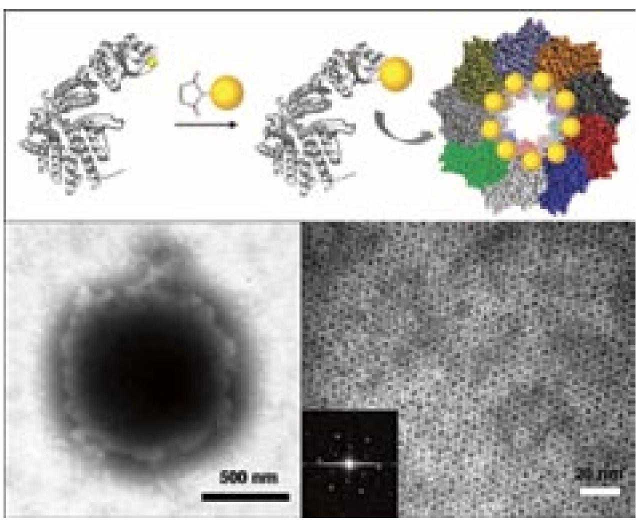


Figure 1. (Top) Genetically engineered proteins bind gold nanoparticles and self-assemble into chaperonins. (Bottom), Chaperonins with nanoparticles held within the pores self assemble into ordered arrays. The distance between each dot, or feature, within the array is many times smaller than the distance between features in devices created using conventional lithography.

The biggest challenge to using nanocarbons is to develop high purity material. The NASA-Ames research team has been working with nanocarbons produced by iron-catalyzed gas phase disproportionation of carbon monoxide (HiPCO process). The raw nanocarbons produced by this process have a high iron content (30%) that needs to be significantly reduced for it to be of value for catalyst impregnation and pollution control applications. This was performed successfully with the iron content being reduced to less than 1% - the lowest reported to-date. Surface characterization of the nanocarbons confirmed the purity and also showed that we had achieved BET surface areas of close to 1600 squared meters per gram. (Cinke et al, Chem. Phys. Letters (2002): volume 365 pp 69–74)

DEVELOPMENT OF THE VAPOR PHASE CATALYTIC AMMONIA REMOVAL PROCESS

Michael Flynn

Water is the single largest resupply requirement associated with human space flight, accounting for 87% by mass of an astronaut's daily metabolic requirement. The Vapor Phase Catalytic Ammonia Removal (VPCAR) system technology represents the next generation in space flight water recovery system. It was designed to accept a combined waste stream (urine, condensate, and hygiene water) and produce potable water in a single step. This compact, module system requires no resupply or maintenance and can fit into a volume comparable to a single Space Station rack. NASA Ames recently completed the development of a human-rated, test version of the VPCAR technology, as shown in Figure 1.

The VPCAR system achieves a mass metric almost an order of magnitude better than the current state-of-the-art water processors. (Mass metric is a technique used to compare candidate technologies by reducing all performance parameters into a single equivalent launch mass metric.) Incorporating the VPCAR technology into human space flight missions could potentially save hundreds of millions of dollars in resupply costs, depending on the specific mission scenario.

Figure 1. VPCAR under construction.

VPCAR is a two-step distillation based water processor that uses of a wiped-film rotating-disk (WFRD) vacuum evaporator to volatilize water, small molecular weight organics, and ammonia. The vapor stream is then oxidized in a vapor phase catalytic reactor to destroy any contaminants. The VPCAR system uses two catalytic beds to oxidize contaminants and decompose any nitrous oxide produced in the first bed. The first catalytic bed oxidizes organics to carbon dioxide and water and ammonia to nitrous oxide and water. This oxidation reactor contains 1 percent platinum on alumina pellets and operates at about 523 Kelvin. The second catalytic bed reduces the nitrous oxide to nitrogen and oxygen. This reduction catalyst contains 0.5% ruthenium on alumina pellets and operates at about 723 Kelvin. The reactor and distillation functions occur in a single modular process step. The process achieves between 97-98 percent water recovery and has no scheduled maintenance or resupply requirements for a minimum of three years.

The VPCAR activity is significant in that it represents the development of the next generation of life support water recovery technology. Ames Research Center's involvement has spanned from the first principle definition to the model development, bench-scale and lab-scale prototype development, and most recently, contract management of the development of a human-rated version of the technology for evaluation for space flight application.

TEMPERATURE-SWING ADSORPTION COMPRESSOR FOR A CLOSED-LOOP AIR REVITALIZATION SYSTEM

Lila Mulloth

Living in space beyond low Earth orbit for extended durations will be possible only in a self-sustaining environment where air, water and food are regenerated. Closing the air loop is one of the important steps among the life support processes. A closed-loop air revitalization system (Figure 1) requires continuous removal of carbon dioxide from the breathable air and an oxygen recovery system to conserve the oxygen from the waste carbon dioxide. Production of oxygen from carbon dioxide is typically achieved by reacting carbon dioxide with hydrogen in a Sabatier reactor. An interface device, such as a compressor, is required to link the carbon dioxide removal system and the Sabatier reactor. Closing the air loop will also significantly reduce the cost associated with the water resupply from Earth. NASA Ames has developed and tested a solid-state compressor that can interface the carbon dioxide removal assembly and the Sabatier reactor for air-loop closure in a spacecraft.

The air revitalization system of the International Space Station (ISS) operates in an open loop mode and relies on the resupply of oxygen and other consumables from Earth for the life support of astronauts. Currently, the excess carbon dioxide that is being removed from the cabin air and the hydrogen that is produced as a byproduct during the water electrolysis for oxygen production are being vented to space. The Carbon Dioxide Removal Assembly (CDRA) of ISS does not have the provision for supplying the waste carbon dioxide to a reduction unit at the required pressure. An additional compressor and a storage device is required to remove the carbon dioxide from the CDRA at a low-pressure, store it, and supply it to the Sabatier reactor at a higher pressure as needed. The need to close the air loop is critical in long-duration transit vehicles and future space habitats where the resupply of consumables may not be practical.

NASA Ames is developing a Temperature-Swing Adsorption Compressor (TSAC) to close the air loop. This compressor will perform the functions of a vacuum pump, compressor, and storage device for the acquisition and delivery of the CO_2 from CDRA to the Sabatier reactor. Unlike a mechanical compressor, the TSAC is a solid-state device that offers quiet and vibration-free operation, long life, and high reliability that are essential for long duration space voyages. In addition, if waste heat is available, the TSAC can operate with minimum or no electrical power. The TSAC has a direct application in closing the air loop in the ISS life support system and is a highly promising technology for the future space habitats and long-duration planetary and transit vehicles.

The TSAC contains two identical cylinders that operate in a cyclical manner. One cylinder acts as a "vacuum pump" that synchronizes with the carbon dioxide removal system while the other acts as a "compressor" that synchronizes with the Sabatier reactor to ensure uninterrupted operation of the air revitalization system components. Low-pressure carbon dioxide from the CDRA is adsorbed on the TSAC chamber that contains cold and regenerated sorbent. The sorbent chamber stores the carbon dioxide until the Sabatier reactor is ready to accept it. The sorbent in the closed chamber is then heated in order to drive the carbon dioxide off the sorbent and thereby increase the pressure to the desired set point. The compressed gas flows into the Sabatier reactor at a controlled rate. Coolant from the spacecraft's thermal control system cools the cylinder back to its initial state, and the process is repeated. A prototype of the TSAC (Figure 2) was built at Ames and successfully tested with a flight-like CDRA at NASA Marshall Space Flight Center. The tests demonstrated the ability of TSAC to operate as an efficient interface device for the CDRA and Sabatier reactor.

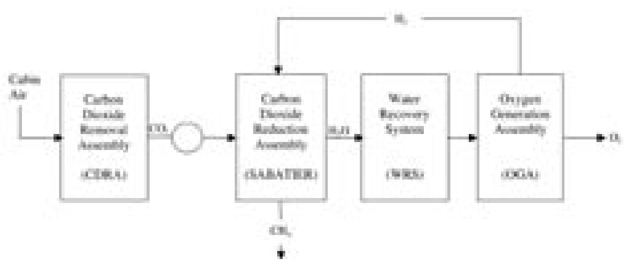


Figure 1. Schematic of closed-loop air revitalization system for a spacecraft.

Figure 2. TSAC prototype developed at NASA Ames Research Center.

Planetary Systems Branch

Overview

The overall research effort in the Planetary Systems Branch is directed at acquiring new, fundamental knowledge about the origins of stars and planetary systems and life itself. These studies are an integral part of NASA's overarching thrust in Astrobiology. Principal research programs include studies of the formation of stars and planets and the early history of the solar system, studies of planetary atmospheres and climate, investigation of the dynamics of planetary disks and rings, work on problems associated with the Martian surface including resource utilization and environments for the origin of life, and other programs (chiefly theoretical) involving stellar and planetary dynamics, radiative processes in stars and the interstellar medium, and investigation of the physical and chemical conditions in molecular clouds and star formation regions. Scientists in the branch also support NASA flight missions through participation on various mission science teams. The primary product of the Branch is new knowledge about the nature of the universe, presented and published in the open literature.

Bruce F. Smith

Chief, Planetary Systems Branch

KEPLER MISSION TO FIND EARTH-SIZE PLANETS: A STATUS REPORT

William J. Borucki, David Koch, Timothy Brown, Gibor Basri, Alan Boss, Donald Brownlee, John Caldwell, William Cochran, Edward Dunham, Andrea Dupree, Edna DeVore, John Geary, Ronald Gilliland, Alan Gould, Steve Howell, Jon Jenkins, Yoji Kondo, David Latham, Jack Lissauer, Geoff Marcy, David Morrison, Tobias Owen, Harold Reitsema, Dmiter Sasselov, and Jill Tarter

Small rocky planets at orbital distances from 0.9 to 1.2 AU are more likely to harbor life than the giant gas planets that are now being discovered with the Doppler-velocity technique. Technology based on transit photometry can find smaller, Earth-like planets that are a factor of several hundred times less massive than Jupiter-like planets. The Kepler Mission is designed to discover hundreds of Earth-size planets in and near the habitable zone (HZ) around a wide variety of stars. It was selected as Discovery Mission #10 in December 2001.

The instrument is a wide field-of-view (FOV) differential photometer with a 100 square degree field of view that continuously and simultaneously monitors the brightness of 100,000 main-sequence stars with sufficient precision to detect transits by Earth-size planets orbiting G2 dwarfs. The brightness range of target stars is from visual magnitude 9 through 14. The photometer is based on a modified Schmidt telescope design that includes field flatteners near the focal plane. Figure 1 is a schematic diagram of the photometer.

Approximately 100,000 target stars must be monitored to get a statistically meaningful estimate of the frequency of terrestrial planets in the HZ of solar-like stars. In particular even if every such star has such a planet, only about 500 planets will be discovered because the geometrical probability that the planets' orbit will be aligned well enough to show transits is only about 0.5%. In the 100 sq degree Kepler FOV, there are approximately 450,000 stars brighter than 15th magnitude. To find 100,000 useful targets, all of these must be classified with respect to spectral type and luminosity class because no catalogs with this information exist. This is a formidable task that must be completed before launch. Hence three small studies have been funded this year to find the quickest and least expensive method. Two of the studies will use multi-band photometry and ground-based telescopes with large fields of view. The third study will use a combination of multi-fiber spectroscopy at a 6.5 m telescope and the results of recently published catalogs of infrared stellar measurements and reduced proper motions to identify and eliminate those stars of little interest. Results of the three studies are due in December.

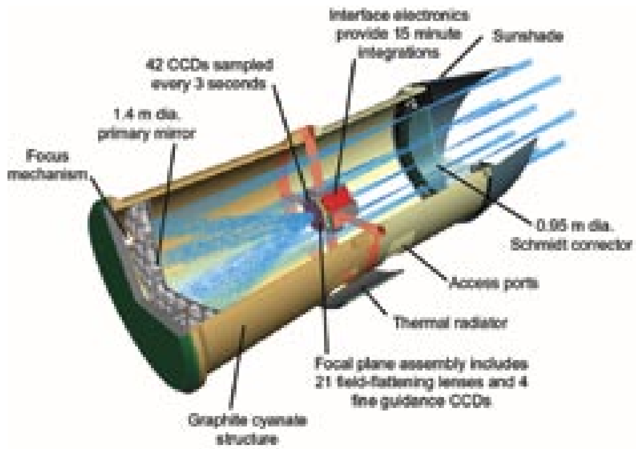


Figure 1. Schematic diagram of Kepler photometer.

Phase B work started in March of 2002. Since then a new management team from the NASA Jet Propulsion Lab (JPL) was chosen to provide overall mission management. The JPL team members have been smoothly integrated with those at NASA Ames and the Ball Aerospace & Technology Corporation. Their addition greatly strengthens the Kepler Mission by providing great depth in mission management and engineering.

In the fall of 2002, 30 CCD detectors were ordered from each of two vendors. This "twin buy" approach insures that the large number of detectors required for the Kepler focal plane will be available even if one of the two vendors runs into difficulties. In April of this year all mechanical grade detectors were received. Minor difficulties were found, but all were acceptable. Delivery of the evaluation grade detectors is expected to start in May 2003. These will be tested to demonstrate that they correctly respond to electronics, have the appropriate sensitivity, and produce photometrically stable results.

Competition to build both the 0.95m Schmidt corrector and the 1.4m primary mirror for the photometer optics was won by the Brashear Corporation in May 2003. Delivery is expected in 2005. Negotiations for other long-lead items such as the Ka- and X-band travelling-wave tube amplifiers (TWTAs) needed for the telemetry link are in progress.

The first major review of the mission, the systems requirement review, will be held this October. In summary, the Kepler Mission is on schedule for a 2007 launch.

PLANETARY RINGS

J. N. Cuzzi, I. Mosqueira, and F. Poulet

Saturn's rings are one of the main targets of the upcoming Cassini mission to Saturn. In addition, rings provide a unique dynamical laboratory for understanding the properties of particle disks, which will help us understand the accretion of the planets.

Models we have developed for the way in which grainy, icy surfaces (or "regoliths") scatter light have been applied to model the composition of Saturn's rings in a quantitative way for the first time. One very interesting result of this research is that the tendency for regolith grains to scatter light in the forward direction, deeper into the surface, has been greatly underestimated in the most popular previous models. This has led to overestimates of the amounts of nonicy contaminants required to be mixed into these surfaces in order to explain their colors. Application of the new models to two "Centaurs", or icy bodies orbiting between Saturn and Uranus, leads to Carbon/Water Ice mass ratios which are 30 times smaller than previously believed. These models, applied to Saturn's rings, imply that only a few percent of the rings can be composed of materials other than water ice (i.e., amorphous Carbon; reddish "Tholin"-like organics). In addition, modeling of newly obtained, very high spectral resolution data from NASA's Infrared Telescope Facility, in combination with these models, indicate that the Carbon is distributed differently on a microscopic level withni the regolith in some rings than in others—perhaps indicating that it was formed in situ by radiation darkening, or that it was more finely pulverized by meteoroid impacts.

Other research has focussed on the origin of the regular satellites of the gas giant planets, which can be considered "miniature solar systems." The research is unique in that it attempts to explain the regular satellite systems of Jupiter, Saturn and Uranus within the same general scheme, merely by varying local conditions such as temperature and gas density. It includes satellitesimal migration due to gas drag and tidal torques, and forms satellites by a combination of "particle-in-a-box" binary accretion and drift augmented accretion in an extended, two-component planetary subnebula. The dense inner disk is set by the location to which the nearby, sun-orbiting gas and debris falls inward, while the much less dense outer disk extends to the location of the irregulars, and arises as a result of later infall from further distances.

This model forms Ganymede and Titan in the inner disk in one to ten thousand years and ten to a hundred thousand years respectively, and Callisto and Iapetus in the outer disk, both in about a million years. Callisto is formed out the volatile-rich condensables present in the extended, low density outer disk; its very long formation timescale is tied to the disk clearing time, which is the time it takes for gas drag to clear the circumplanetary disk of solids. The different formation material and timescale of Callisto relative to Ganymede may explain the high volatile content of Callisto compared to Ganymede, as well as Callisto's partially differentiated state (in contrast, Ganymede is fully differentiated). Formation of Hyperion in resonance can be explained by the steep density gradient between the inner and outer disks, as had been suggested without context by some earlier studies. The model also makes several predictions about the composition and interior structure of Titan, Iapetus, the icy inner saturnian satellites and the rings, which may soon be tested by Cassini.

PARTICLE-GAS DYNAMICS IN THE PROTOPLANETARY NEBULA

J. N. Cuzzi, R.C. Hogan, S. S. Davis, and A. R. Dobrovolskis

"Primitive" or unmelted asteroids, from which the terrestrial planets were built, are represented in the meteorite record as a vast and complex set of "chondrites."

The interpretation of this unique look into the environment preceding planet formation has suffered for lack of a coherent theoretical context. Accretion of these primitive chondrites from small grains and mm-sized, melted silicate "chondrules" almost certainly occurred in the presence of gas, where subtle feedback effects occur between gas and particles.This research focusses on theoretical modeling of particle-gas interactions in turbulent nebula flows, and understanding meteorite properties in the light of these models.

Building on past results in this line of research, Ames researchers have developed new analytical models of particle velocities in the early solar nebula. These models encapsulate complex physics into simple, but still rigorous, closed-form analytical expressions suitable for general use. One of the first uses of the new results has been as part of a new model of the formation and redistribution of one key component of meteorites—the oldest, highest-temperature mineral condensates called Calcium-Aluminum-rich inclusions (CAIs). The models predict a significant enhancement of the inner nebula in silicates and Carbon for the first hundred thousand years of nebula history, due to drifting meter-sized rubble. This region, for this time, is likely to be the CAI formation zone. It is becoming evident that CAIs, found ubiquitously in primitive chondrites, are 1–3 million years older than the bulk of the other mineral objects in the same rock. It has long puzzled meteoriticists as to why these older fragments are not lost into the sun during this several million year hiatus. Our models show that turbulent diffusion of CAIs outwards in the nebula, subsequent to their formation, can explain their persistence for several million years. The enhancement of the formation zone in silicates explains the abundance of CAIs in meteorites quantitatively, and its enhancement in Carbon apparently helps explain their chemical and isotopic properties.

This year, Ames researchers also developed a novel cascade model for turbulence, which is capable of reproducing the statistical properties of fully 3D direct numerical simulations (DNS) and extending them to far higher Reynolds numbers. The goal of the model is to make quantitative estimates of the tendency of turbulent concentration of particles to produce planetesimals with the observed properties. Our model is a two-phase, coupled cascade which calculates both particle concentration and local vorticity, with their spatial correlations included. These two properties determine the tendency towards gravitational instability of dense regions. Furthermore, the effects of particle mass loading on the cascade—leading to a tendency for particle concentration to saturate at some high level - are modeled using characteristic "partition rules" obtained from 3D simulations of turbulence under mass loaded conditions. The cascade code is running on Ames' Origins 2000 1024 node machine, and is capable of reaching Reynolds numbers of over a million with reasonable run times. For comparison, 3D DNS models struggle to reach Reynolds numbers of several thousand.

THE PASCAL MARS SCOUT MISSION

Robert M. Haberle

The next major advance in our understanding of the meteorology and climate of Mars will come from in-situ measurements taken by a global network of long-lived landers. The National Research Council has recommended to NASA that in developing its long term science goals for Mars exploration, such a mission should be given high priority. During most of fiscal year 2002 Ames Research Center, along with industry partners Ball Aerospace, Lockheed Martin Advanced Technology Center, and ITT Aerotherm Corporation, developed a network mission concept to propose to NASA's Mars Scout program. The mission is named after Blaise Pascal, the 17th century French scientist who pioneered measurements of atmospheric surface pressure, the most important meteorological parameter.

The Pascal mission delivers 18 small weather stations to the surface of Mars. The weather stations are distributed all around the planet so global scale phenomena can be sampled. Each station conducts meteorological measurements for at least 3 Mars years (a Mars year is equivalent to 687 Earth days). These measurements include pressure, temperature, sky opacity, wind speed, and water vapor concentration. A panoramic camera system periodically images the surrounding terrain to look for changes in the scene due to wind activity. In addition to these measurements, each weather station

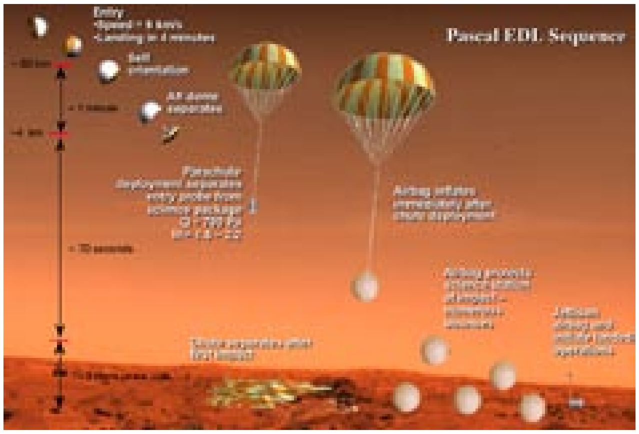


Figure 1. Pascal entry, descent, and landing (EDL) sequence.

measures the temperature structure of the atmosphere, and takes pictures of the ground during its descent to the surface. All operations are autonomous. Communications to and from the Earth takes place through a relay orbiter provided by NASA's Mars Exploration Program or those from other countries.

A carrier spacecraft begins releasing and targeting the probes to the surface of Mars when it is about 40 days from encountering the planet. The targeting and release sequence takes about 15 days to complete. Figure 1 shows the entry, descent, and landing sequence. After releasing all the probes, the carrier spacecraft flys by Mars and begins to orbit the sun. Each probe enters the atmosphere at an altitude of approximately 150 km. The probes orient themselves so that the aeroshell is facing forward. The aeroshell provides thermal protection as the probes slow down in the atmosphere. At 10 km altitude, a parachute is deployed to further slow the probes to approximately 25 meters per second (50 miles per hour). Just before impact an airbag inflates and the parachute is jettisoned. After several bounces the probe comes to rest and the airbag is jettisoned. The camera system is then deployed and autonomous operations commence.

The Pascal mission seeks to understand the long-term global behavior of weather systems on Mars, how they interact with the surface, and how they control the planet's climate system. The science objectives are (1) measure the seasonal cycles of dust, water vapor, and carbon dioxide, (2) measure the surface signature of the planet's weather systems, (3) understand how these systems control the planet's climate and modify its surface, and (4) provide a basis for comparative planetary meteorology. The Pascal mission provides a long-term continuous presence on the surface of Mars not possible in previous missions.

THE CENTER FOR STAR FORMATION STUDIES

D. Hollenbach and K. R. Bell

The Center for Star Formation Studies, a consortium of scientists from the Space Science Division at Ames and the Astronomy Departments of the University of California at Berkeley and Santa Cruz, conducts a coordinated program of theoretical research on star and planet formation. The Center, under the directorship of D. Hollenbach (NASA Ames), supports postdoctoral fellows, senior visitors, and students, meets regularly at Ames to exchange ideas and to present informal seminars on current research, hosts visits of outside scientists, and conducts a week-long workshop on selected aspects of star and planet formation each summer.

In June 2002 the Center, along with the Institute of Astronomy and Astrophysics in Taiwan, co-hosted an international workshop entitled "Magnetohydrodynamics, Radiation Diagnostics, and Chemistry of Star Formation," which was held in Taiwan. The weeklong workshop had approximately 150 attendees, and included an invited talk by D. Hollenbach on "Molecular and Dust Emission from Disks Around Low Mass Stars"

One focus of the NASA Ames portion of the research work in the Center in 2002 involved the study of the ultraviolet radiation field in galaxies which is produced by relatively short-lived massive stars. Stars in galaxies form by the gravitational collapse of portions of giant molecular clouds (GMCs), and the star formation in these GMCs produces a range of stellar masses, including massive stars with masses 10 to 100 times as massive as the Sun. Although these stars are less numerous than solar-type stars, they are incredibly luminous, nearly 105 times as luminous as the Sun, and they dominate the production of ultraviolet radiation in galaxies. The GMCs form out of an assemblage of more diffuse, cold atomic clouds in galaxies, and the amount of diffuse cold clouds is determined by the ultraviolet radiation field. If the ultraviolet radiation field is high, the heating caused by these energetic photons will warm the cold clouds to extremely high temperatures of 104 K and cause them to expand and dissipate. In this way, the rate of star formation in a galaxy is self-regulated. If stars form too rapidly, there will be a large population of massive stars, a resultant high ultraviolet field, and a consequent destruction of the very clouds which lead to star formation. Hence, the star formation rate will be forced to slow down. On the other hand, if the star formation rate is low, the ultraviolet field is low, and there is little heating of the diffuse gas in the interstellar medium. In this case, the gas cools, forms copious cold clouds, which conglomerate to form GMCs, and which then ultimately lead to higher star formation rates.

Another focus of the Ames portion of the Center research in 2002 involved a study of dust particles at the surface of a protoplanetary disk. Radiation from this layer produces infrared emission that reveals mineralogical, chemical, and morphological properties of the dust. Long term monitoring of a dozen young star/disk systems has revealed several whose infrared emission changes dramatically from month to month. This unexpected short term variability may mean that both dust population and disk structure are evolving very rapidly in the planet-forming regions of young Sun-like systems.

The theoretical models of the Center have been used to interpret observational data from such NASA facilities as the Infrared Telescope Facility (IRTF), the Infrared Astronomical Observatory (IRAS), the Hubble Space Telescope (HST), and the Infrared Space Observatory (ISO, a European space telescope with NASA collaboration), as well as from numerous ground-based radio and optical telescopes. In addition, they have been used to determine requirements on future missions such as the Stratospheric Observatory for Infrared Astronomy (SOFIA) and the Space Infrared Telescope Facility (SIRTF).

HEARING THE LESSONS BROWN DWARFS TEACH

Mark Marley, Richard Freedman

One of the central goals for NASA's Space Science Enterprise is the direct detection of extrasolar planets. Jupiter-like planets are an easier target than terrestrial planets, of course, and as such will serve as a stepping stone on the path to finding "pale blue dots," or extrasolar Earth-like planets. Even obtaining the first image of an extrasolar Jupiter will require large ground or space based telescopes, a new generation of instruments, and an optimal strategy. In fact one of the key science goals of the James Webb Space Telescope is to directly image extrasolar giant planets in the solar neighborhood. The strategy is to image these planets at the favorable wavelength of five microns, where models predict the planets to be particularly bright and the glare from their primary star to be less troublesome.

Although no giant planets have yet been imaged, hundreds of brown dwarfs have been found. These objects, which are more massive than planets, but less massive than stars, serve as pathfinders to the extrasolar giant planets. They have roughly the same radii, the same composition, and the same atmospheric temperature conditions as, at least some, extrasolar planets. As such they provide test cases which illuminate the optimal observing strategy.

At the conditions prevalent in cool brown dwarf atmospheres, chemical equilibrium arguments suggest that most carbon atoms should be found in the form of methane, CH_4. Methane, along with water and ammonia, the other major atmospheric constituents, absorb relatively little near five microns. This absorption minimum is responsible for the opening of the "window" in this spectral region. The window allows bright flux from deeper, hotter regions of the atmosphere to escape to space. Thus the prediction that extrasolar giant planets should be bright at five microns. However, a key result from the past year of observations and interpretation of brown dwarfs has been that these objects are dimmer than predicted by models in this crucial spectral region.

The most likely explanation for this unexpected diminution in brightness is an enhanced abundance of carbon monoxide, CO, in these atmospheres. Although methane is the favored reservoir of carbon at low temperatures high in the atmosphere, CO is favored deeper in the atmosphere. Strong vertical flows in the atmosphere can transport CO from the deep, unobservable, regions up to the observable atmosphere. Once there the tendency of carbon monoxide to absorb near five microns muffles the otherwise bright emitted flux. A similar phenomenon is seen at Jupiter where CO is detectable in this same spectral region.

The fact that some cool brown dwarfs are substantially (by up to 60%) dimmer than expected implies that this same phenomenon may be ubiquitous, and also affects the atmosphere of extrasolar giant planets. If so the planets will be dimmer and more difficult to detect than had previously been expected.

Continuing research will focus on better understanding the reason for the flux diminution in brown dwarfs and providing guidance for efforts to directly detect extrasolar giant planets.

CLUSTER DETECTION IN GALAXY SURVEYS

Jeffrey D. Scargle, Christopher E. Henze, Creon Levit, Michael Way, Bradley Jackson

This collaboration developed a novel way to detect and characterize structure in three dimensional point data, and applied the methodology to analyze large new data sets from astronomical surveys of the constituents of the Universe. This application resulted in an objective procedure for identifying galaxy clusters without imposing assumptions about cluster shape, and without fixing ahead of time the number of clusters - thus removing limitation affecting most previous cluster detection studies.

The procedure is based on a 3D segmentation model, in which the data space is partitioned into subregions such that the point density is well modeled as being constant over each such subregion. The computational procedure is to find the optimum such partition, meaning the one that maximizes a goodness of fit quantity. The Bayesian posterior probability of the model, given the point data, was adopted as this fitness measure.

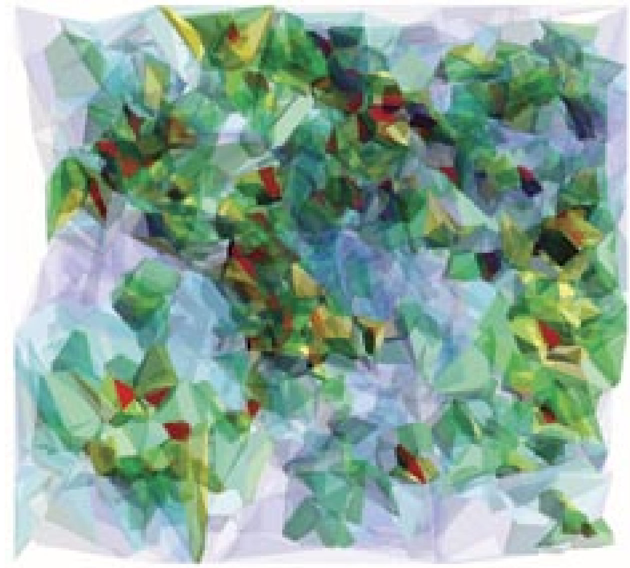


Fig. 1: Results of the segmentation analysis of a small cube of data from the Sloan Digital Sky Survey Early Release Data. The color scale indicates density of galaxies per unit volume of space, with red being the highest density, then yellow, green, and light blue, with violet being the least dense (and roughly representing a uniform background of non-clustered galaxies on which the other structures are superimposed.

The complexity of the space of possible models was reduced by positing that the partition elements consist of finite collections of data cells - that is, regions of the data space closest to a given data point, the so-called Voronoi tessellation of the space. This excellent approximation reduces the size of the search space from highly infinite to a finite one—albeit exponential in the number of data points.

The solution to this combinatorial optimization problem is obtained by a simple adaptation to higher dimensionality of an exact 1D algorithm developed in an earlier phase of the work. The adaptation is based on a mathematical result, called the intermediate density principle—which allows the data cells in any dimensional space to be ordered by cell volume and then treated as a 1D sequence. The final algorithm finds the global optimum partition of the data in time proporational to the square of the number of data points.

The algorithm was applied to the early release data from the Sloan Digital Sky Survey (www.sdss.org). A small sample result is shown in the first figure. The raw data consist of the positions on the sky and redshifts of a large sample of galaxies. Converting the redshifts to distances, using the Hubble relationship, yields a true 3D distribtion of tens of thousands (ultimately millions when the survey is complete) of galaxies. The optimal partition in to collections (called blocks) of 3D Voronoi cells, colored according to the spatial density of galaxies averaged over each block, are shown in the figure. We are experimenting with scientific visualization techniques to render the true distribution more comprehensible, including the use of the NAS HyperWall to explicate correlations between the spatial, spectral, color and brightness data available for each galaxy.

THE CHEMISTRY AND MINERALOGY OF ATACAMA DESERT SOILS

Brad Sutter

The Atacama Desert of northern Chile is the driest desert in the world. While Mars is vastly more dry and cold than the Atacama, the Atacama environment may be one of the best terrestrial Mars analog environments accessible to researchers. The objective of this work was to examine the soils of the hyper-arid Atacama Desert to provide insight as to what soil properties maybe found on Mars.

Three soils were examined that occur along a south to north transect (Copiapo → Altimira → Yungay) in the Atacama that coincides with decreasing moisture levels (~15mm to ~2 mm yr^{-1}, south to north). Total chemical analyses were used to calculate strain (i.e. volume change) and the open-system mass-transport function. The Yungay and Altimira soils expanded over 400% while the Copiapo soil collapsed by as much as 48%. The expansion of the Yungay and Altimira soils may be the result of the additions of sulfate, nitrate, and chloride from aerosol inputs from wind redistribution of playa salts, volcanic activity, and marine influences. Apparently, the higher level of precipitation at the Copiapo site caused leeching, and the sulfate, nitrate, and chloride additions could not accumulate to levels high enough, thus the Copiapo soil collapsed. The lack of significant precipitation at the Yungay and Altimira soils allows for additions of sulfate, nitrate, and chloride to remain, which resulted in soil expansion.

The results of this work suggest that there is a critical water balance for soil formation (precipitation – evapotranspiration) at which the long-term accumulation of atmospherically-derived elements (e.g., sulfate, nitrate, and chloride) exceeds weathering losses, and landscapes undergo continual dilation (e.g., Yungay soil) as opposed to collapse (e.g, Copiapo soil). The critical climatic cutoff point is likely to be quite arid. In the Atacama Desert, the crossover point between the accretion vs. the loss of soluble atmospheric inputs such as sulfate is somewhere between 2 and 15 mm of precipitation per year. Elevated levels of sulfur and chlorine found at the Viking and Pathfinder sites suggesting aerosol input coupled with the extreme aridity of Mars indicates that Martian soils may have undergone volumetric expansion similar to what has occurred in the Atacama.

Currently, the rare earth elements of the above soils as well as soil chemical data just received from soil horizons deeper than what was discussed above are being examined to provide more insight into the soil expansion and contraction properties of Atacama soils. Future work will examine Atacama soils developed on volcanic materials farther from the coast in an effort to obtain a better analog to Mars soils.

HEAT FLOW AND DEGASSING IN MANTLE CONVECTION

Kevin Zahnle, Norman H. Sleep, and Francis W. H. Nimmo

That the Earth's mantle convects is not in doubt. But whether it convects as a whole, in layers, or in some more complex pattern is a matter of debate. In whole mantle convection the continents and atmosphere are extracted from the mantle as a whole. The remaining "depleted" mantle is to first approximation statistically well-mixed and fairly sampled by volcanism. More subtle views of whole mantle convection regard the mantle as a poorly stirred cauldren of primitive materials, depleted materials, and convectively-entrained materials from the surface (e.g. subducted continental materials and subducted MORB) and from the core-mantle boundary. In layered convection the mantle convects in two layers, which may be loosely termed "upper mantle" and "lower mantle." By construction the lower mantle is not easily depleted and does not easily degas. In traditional layered convection, the layering is identified with and possibly caused by (or at least modulated by) the solid state phase transition that occurs 660 km below the surface. More modern versions of layered convection move the barrier to mixing to much greater depths and have asserted that compositional differences between upper and lower mantle materials can maintain distinctive unmixed mantle reservoirs.

A great many geophysical, seismological, and geochemical arguments have been made to all sides of this debate that do not need to be summarized here. Suffice it to say that seismological evidence against layering at 660 km, the traditional boundary between the upper and lower mantle, is strong, yet good indirect arguments for layering remain. One such argument involves a heat flow paradox: Earth seems to be cooling much faster than it is being heated by the decay of radioactive elements. (The important radioactive elements are uranium, thorium, and a rare isotope of potassium.) Such a mismatch is not expected in conventional whole mantle convection, but it is reasonable in layered convection, because the lower mantle can better store old heat. Second, radioactive decay produces, among other products, the inert gases helium and argon. The amount of argon in the atmosphere and the amount of helium currently being degassed from the Earth's mantle are both smaller than expected of a well-mixed mantle. The mantle helium flux in particular agrees with what is expected from a small isolated upper mantle. A well-known but ambiguous third argument for layering exploits the relative fluxes of radiogenic (^{4}He) and nonradiogenic (^{3}He) helium. In this argument relatively high ^{3}He/^{4}He ratios associated with Ocean Island Basalts (OIBs) are attributed to high ^{3}He/^{4}He material from the lower mantle. The idea is that the lower mantle is less degassed, and so retains a relatively higher amount of the nonradiogenic ^{3}He. This is something of a pyrrhic victory given that the quantity of helium in OIBs is smaller, and sometimes much smaller, than in the more voluminous Mid-Ocean Ridge Basalts (MORBs). The observed relationship is opposite what one expects from a helium-rich lower mantle source.

The failure to establish the existence of a material boundary at 660 km has led layering's advocates to consider alternative topologies. These are loosely lumped together under the label of "lava lamp layering." The key features of these newer models is that the upper mantle is made bigger and deeper, the lower mantle shrinks accordingly, and the distinction is maintained by modest compositional differences. (The lava lamp itself is a misleading but established analogy, misleading because the lava lamp comprises immiscible fluids but the mantle does not.) The new layering represents something of a compromise. It retains in diluted form most of the advantages and the disadvantages of both of its antecedents.

We construct self-consistent degassing and thermal history models for Earth in whole mantle and lava lamp style convection. Whole mantle solutions for argon, helium, CO_2, and the temperature of the Archean upper mantle can be obtained only if (i) helium and argon are some 4–6 times more compatible with the mantle (i.e. more readily retained by the mantle during magmatic processes) than is typical of incompatible "elements" such as CO_2; and (ii) heat flow has been roughly constant over geologic history. The sense of paradox in whole mantle convection stems from (i) the presumption that a rare inert element ought to degas as agressively as an extremely incompatible element; and (ii) the expectation, based on applying the conventional equations of parameterized convection to plate tectonics, that heat flow is strongly coupled to the mantle's temperature in a way that guarantees that heat flow tightly tracks the heating provided by the decay of radioactive elements. Neither of these presumptions is founded well enough to rule out whole mantle convection. The newer versions of layered convection, in which the depleted (upper) mantle comprises ~60% of the whole, may seem better. These allow higher noble gas degassing efficiencies, although still less than half that of CO_2. By setting the ratio of upper to lower mantle to 60:40, the new layering gives self-consistent abundances for Th, U, and K in the continents, MORBs, and lower mantle. This addresses a problem that whole mantle convection can address only by making recourse to heterogeneities. As in whole mantle convection, the new layered convection requires that heat loss be a weak function of mantle temperature. This is a paradox that apparently cannot be resolved by mantle topology alone but may instead require a more subtle understanding of how plate tectonics actually work.

Exobiology Branch

Overview

The Branch's research focuses on the advancement of the scientific understanding of the origin and distribution of life by conducting research on the cosmic history of biogenic compounds, prebiotic evolution, and the early evolution of life. This is accomplished via laboratory experiments, theoretical studies/computational modeling, and field investigations. Branch personnel are also involved in the development of flight instruments, experiments, and small mission definition with particular emphasis being placed on studies of Mars and the development of instrumentation for martian flight missions. Several Branch scientists are part of a task module that is a component of the Ames membership in the Astrobiology Institute. Branch scientists provide expertise in exobiology, astrobiology, planetary protec-tion, and other areas of planetary science to NASA Headquarters and external review and advisory panels, and some serve as editors and associate editors of scientific journals.

Exobiology studies includes the history, distribution, and chemistry of biogenic elements in the solar system; prebiotic chemical evolution and the origin of life; and the history of Earth's early biosphere as recorded in microorganisms and ancient rocks. The research is conducted both on Earth and in space. The Branch also serves as the center of expertise within the agency for issues of planetary protection. As the agency lead center in exobiology, Branch exobiologists exercise a leadership role in NASA's Exobiology Program through program planning, performance reviews, advisory services to related NASA programs, and external relations.

David F. Blake

Chief, Exobiology Branch

DEFINITIVE MINERALOGICAL ANALYSIS ON MARS

David Blake and Philippe Sarrazin

The search for evidence of life, prebiotic chemistry or volatiles on Mars requires the identification of rock types that could have preserved these. Anything older than a few tens of thousands of years will either be a rock, or will only be interpretable in the context of the rocks that contain it.

The key role that definitive mineralogy plays is a consequence of the fact that minerals are thermodynamic phases, having known and specific ranges of temperature, pressure and composition within which they are stable. More than simple compositional analysis, definitive mineralogical analysis can provide information about pressure/temperature conditions of formation, past climate, water activity, the presence of biologically significant gases and the like.

Mineralogical identification—the determination of *crystal structure*—is a critical component of Mars Astrobiological missions. Definitive mineralogical instruments have never been deployed on Mars, and as a result, not a single rock type or mineral has been identified with certainty.

Minerals are defined as unique structural and compositional phases that occur naturally. There are about 15,000 minerals that have been described on Earth. There are likely many minerals yet undiscovered on Earth, and likewise on Mars. If an unknown phase is identified on Mars, it can be fully characterized by structural (X-ray Diffraction, XRD) and elemental (X-ray Fluorescence, XRF) analysis without recourse to other data because XRD relies on the first principles of atomic arrangement for its determinations. Diffraction is the principal means of identification and characterization of minerals on Earth.

The CheMin II XRD/XRF instrument (so called because it is capable of CHEmical and MINeralogical analysis) is capable of quantitative mineralogical analysis. The original prototype has been modified (and made portable) by replacing the Philips-Norelco tube tower with an Oxford Instruments small-focus X-ray source (figure 1). In the current version, the small-focus source (70 µm diameter) and a 30 µm final aperture yield a beam diameter at the sample of ~100µm. A wide variety of minerals and rocks has been analyzed utilizing 40 KV accelerating voltage and 0.25 microamps beam current (10 watts). Interpretable patterns of single minerals can be obtained in less than an hour and quantifiable patterns of complex rocks can be obtained in a few hours.

Quantitative mineralogical analyses have been obtained for a variety of minerals using the CheMin II prototype. Refinements have been made of apophylite (a zeolite), limestone, limestone-evaporite, San Carlos olivine, the Mars meteorite Zagami and many others. Calculated cell parameters for the San Carlos olivine from CheMin data are 4.76, 10.24, and 5.99 Å, yielding a composition of Fo90 - Fo95 (figure 2).

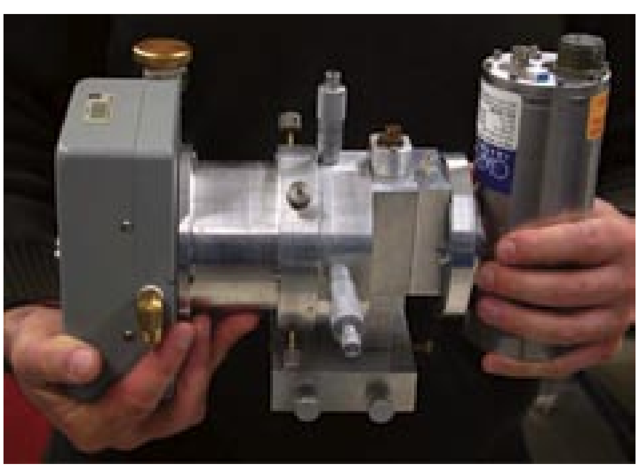


Figure 1: CheMin II instrument

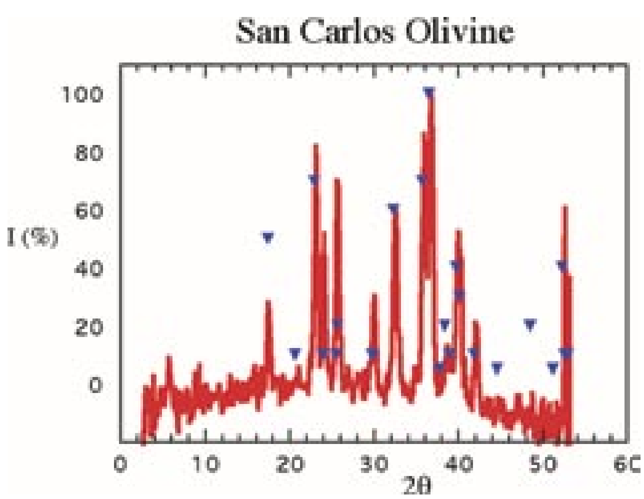


Figure 2: Diffractogram of CheMin olivine data (red) vs. positions & intensities of forsterite standard (blue triangles)

A third prototype (CheMin III) is under construction that will utilize a small-focus (45 µm) Co X-ray source, an ambient pressure sample insertion mechanism, and an air-cooled, vacuum sealed, 1K X 1K deep-depleted CCD. Deep-depletion will increase the quantum efficiency (QE) for diffracted X-ray detection from 0.05 to nearly 0.50, yielding a 10-fold increase in count rate. The instrument will be operable from a laptop computer running Labview™ software.

CARBON ISOTOPIC FRACTIONATION ASSOCIATED WITH CYANOBACTERIAL BIOMARKERS: 2-METHYLHOPANOIDS AND METHYL-BRANCHED ALKANES.

Linda L. Jahnke, Tsegereda Embaye and Roger E. Summons

Biomarker analysis of ancient organic sediments has demonstrated the dominance of cyanobacterial ecosystems going back in geological time to 2700 Ma. The presence of 2-methyl-hopanoids and methyl-branched alkanes serve as biomarkers for this important group of oxygenic photosynthetic bacteria both in geological samples and in contemporary environments. Knowledge of the molecular structures and the carbon isotopic compositions of individual biomarkers might allow recognition of source organisms and environmental conditions. Cyanobacteria have been the significant primary producers throughout most of Earth's history, but little is known about the molecular diversity of their lipid biomarkers or the effects of carbon isotopic fractionations associated with the biosynthesis. We have focussed our study on several pure cultures which synthesize a variety of branched alkanes, and 2-methylhopanoids. Two of these cyanobacterial cultures, *Chlorogloeopsis fritschii* and *Phormidium luridum*, have been obtained from culture collections. Both organisms contain several distinct cyanobacterial biomarker lipids (Fig. 1).

Our work has also involved analysis of a collection of natural microbial mats constructed by fine filamentous cyanobacteria, the coniform mats found in the Midway Geyser Basin of Yellowstone National Park. These mats are considered the best analog for the fossil conophytons, a type of stromatolite dating back 3450 Ma. From these mats, other *Phormidium* cyanobacteria have been isolated, and their phylogenetic relatedness and lipid biomarkers characterized. It is our hope that this study will elaborate links between Phormidium and conophyton stromatolites.

Pure culture studies: Cyanobacteria were grown in feed-batch cultures with a constant gas flow, either high CO_2 (generally 1% v/v) or atmospheric air. Little difference was observed for ^{13}C-discrimination associated with growth on 1% CO_2 for three individual cyanobacteria, with biomass ranging from 21.6 to 22.4‰. The bacteriohopanepolyol (BHP) was generally depleted relative to biomass by 4.0 to 7.4‰ with 2-methyl-BHP often somewhat heavier than non-methylated BHP by 2 to 3‰. This relationship did not appear to depend on the level of CO_2 provided to the culture for growth.

The isotopic composition of alkanes was more complex and depended on carbon chain length and methyl-branching. Generally for each individual cyanobacterium, longer chain and methylated alkanes were heavier

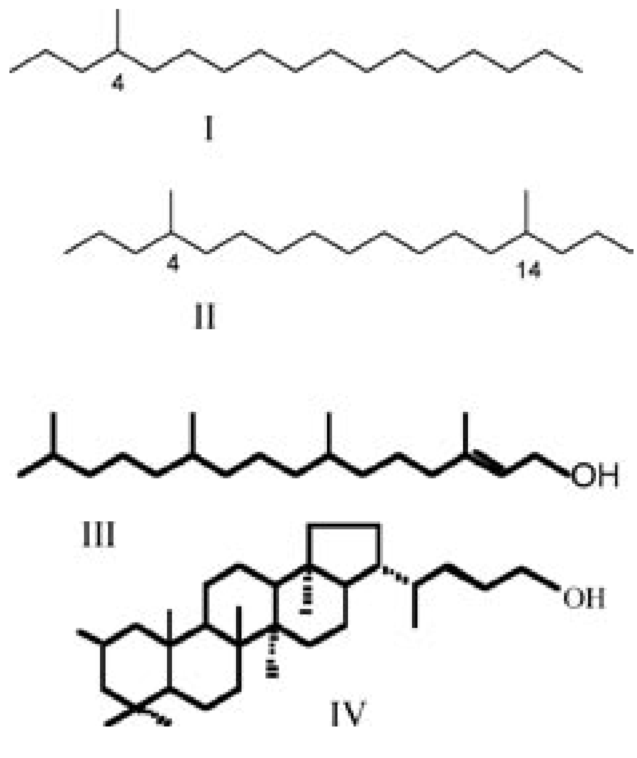


Fig. 1. Lipid biomarkers isolated from Chlorogloeopsis fritschii. *Branched alkanes 4-methyl-octadecane (I) and 4,14-dimethyloctadecane (II). Isoprenoid lipids represented by chlorophyll derived phytol (III) and BHP derived 2-methylhopanol (IV).*

than their shorter, normal chain counterparts. In *C. fritschii* grown with 1% CO_2, n-C_{17} was depleted by 12.1‰ relative to biomass, while the 4-methyl- and 3-methylheptadecanes were 8.7 and 8.0‰, and the 4,14-dimethyl- and 3,14-dimethylheptadecanes were 2.4 and 2.9‰, respectively. A 5-methyl-octadecane present in low abundance (~3% of alkanes) was also relatively depleted, particularly in relation to monomethyl heptadecanes (Fig. 2). Similarly, in an air sparged P. luridum, n-C_{17} was depleted by 10.5‰ relative to biomass, and the 7-methyl- and 7,11-dimethylheptadecanes by 5.6 and 4.5‰, respectively.

The biomarker composition of the cyanobacteria isolated from Yellowstone coniform mats varied considerably. These cyanobacteria were predominately of the *Phormidium*-type and formed three distinct groups based both on lipid biomarker composition and 16S rRNA sequence similarities. 16S rRNA gene sequence analysis indicated that the three groups were closely related to one another and to *P. luridum*. Although these *Phormidium* groups were closely related, lipid composition varied widely. The group represented by *Phormidium* RCO synthesized only straight chain alkanes, primarily n-C_{18} and n-C_{19}, and no hopanoids. *Phormidium* RCG, which represented the second group of isolates, contained n-C_{17} and large amounts of methyl-branched alkanes (7-methyl- and 7,11-dimethylheptadecanes) similar to those found in *P. luridum*, but only a C_{32} BHP (as IV° Fig 1). The biomarker composition of the last group, represented by Phormidium OSS4, was the most complex. The major BHPs were a 2-methyl-C_{31} and a desmethyl-C_{31} with lesser amounts of the C_{32} homologs. The alkanes extended from n-C_{16} to n-C_{22} with a variety of methyl-branched alkanes. The alkane composition of *Phormidium* OSS4 was also affected by growth temperature. In the 30 to 45°C range, mid-chain methyl-alkanes were the major constituents of the hydrocarbon fraction. A small amount of dimethyl-alkane was also present, primarily in a culture grown at 30°C. The straight chain and 2-methylalkanes increased with higher growth temperatures and were dominant in cells grown in the 50 and 55°C range. The isotopic relationships among biomarkers were generally similar to those described above. In one culture grown at 55°C, the fractionation factor ($\varepsilon_{biomarker}$) for individual alkanes

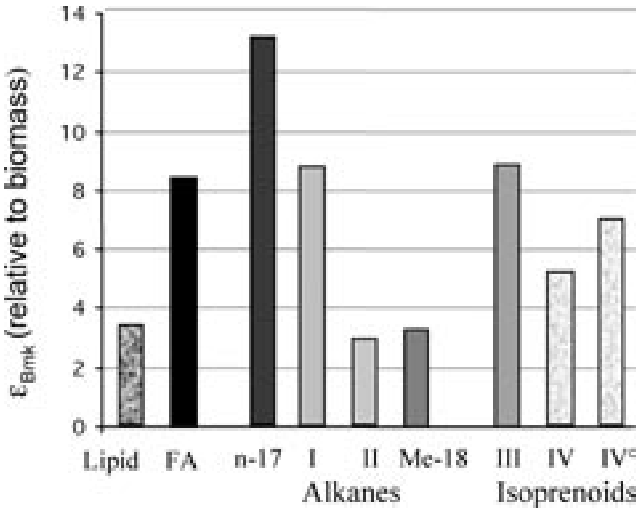


Fig. 2. Carbon isotopic composition of lipid biomarkers isolated from C. fritschii *grown with 1%* CO_2 *where the fractionation factor,* $\varepsilon_{biomarker}$*, is calculated for the lipid components relative to biomass and = (a-1)1000. Normal (n-17) heptadecane and 5-methyloctadecane (Me-18). Numerals refer to structures in Fig. 1, IV° is the desmethyl equivalent of IV, a* C_{32} *hopanol.*

relative to biomass ranged from 8.1‰ for n-C_{17} to -0.6‰ for n-C_{21} and 2.1‰ for 2-methyloctadecane to –0.6‰ for 2-methylicosane. There was also a suggestion of increased fractionation associated with alkane synthesis as the growth temperature was increased with an overall e value obtained by mass balance of 5.5‰ for a 30°C culture and 2.1‰ for a 55°C culture.

Environmental studies: The biomarker composition of the coniform mats varied considerably depending on the environmental setting, but generally contained both 2-methyl-BHP, C_{31} and C_{32} types, and methyl-branched alkanes, primarily the 7-methyl-heptadecane and 7,11-dimethylheptadecane. As with pure culture studies, the monomethyls- were somewhat more depleted (ε = ~11‰) relative to total organic carbon (TOC) than the dimethyls (ε = ~9‰). Isoprenoid lipids were generally more enriched in ^{13}C than alkanes. Values for chlorophyll associated phytols and the desmethylhopanols (C_{31} and C_{32}) were both generally in the 5 to 6‰ range. As with pure cultures, the 2-methylhopanols were 1 to 2‰ heavier than their desmethyl homologues.

PENNING IONIZATION ELECTRON SPECTROSCOPY (PIES)

Daniel R. Kojiro, Valery A. Sheverev, Nikolai A. Khromov, and Norishige Takeuchi

Exobiology flight experiments require highly sensitive instrumentation for the in situ analyses of volatile chemical species that occur in the atmospheres and surfaces of various bodies within the solar system. The complex mixtures encountered place a heavy burden on the analytical instrumentation to detect and identify all species present. The minimal resources available on-board for such missions mandate that the instruments provide maximum analytical capabilities with minimal requirements of volume, weight and consumables. The objective of this research is to develop analytical technologies for the analysis of complex extraterrestrial mixtures of interest to Astrobiology. These are often complex mixtures with many components ranging in concentration from a few parts-per-billion to a few per cent. Typical analytical requirements are:

- *Universal response*
- *Part per billion sensitivity*
- *Response range of over 106*
- *Instantaneous recovery time (quick analyses).*

Ideally, the instrument should be able to meet these analytical requirements while operating under severely restricted conditions. It should be:

- *Rugged*
- *Tiny*
- *Use little or no power for operation or for maintenance*
- *Require few consumables (carrier gas).*

A new technique being investigated is Penning Ionization Electron Spectroscopy (PIES). PIES measures the energy of electrons released from sample molecules ionized by collisions with metastable helium (Penning Ionization). From that measurement, the ionization potential of the sample molecule is determined and is used to identify the molecule. PIES has the potential of providing both sample detection and direct molecular identification of a gaseous species.

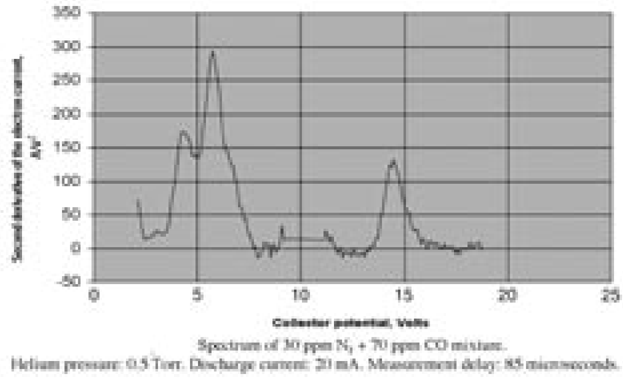


Figure 1 is a PIES spectrum of a mixture of N_2 and CO, (both molecular weight 28). The peak at 14.4 electron volts is from ionization from two metastable helium atoms. The primary N_2 peak is at 4.2 electron volts and for CO the primary peak is at 5.8 electron volts. Although both gases have the same molecular weight, they produce separate identifying peaks in the PIES spectrum.

THE ORIGIN AND EARLY EVOLUTION OF MEMBRANE PROTEINS

Andrew Pohorille and Michael Wilson

The formation of protocells—membrane enclosed structures endowed with ubiquitous cellular functions—was a central step in evolution from inanimate to animate matter. Many essential cellular functions are performed by proteins embedded in membranes. These proteins or protein complexes are among the largest macromolecular structures found in cells and their mode of action is often complicated and subtle. This creates a difficulty for explaining the origin of cells. If functions of membrane proteins were essential to the existence of even the simplest cell it must be explained how they could have been performed, even less efficiently or selectively, by simple precursors of proteins - peptides.

On the basis of a series of detailed molecular dynamics computer simulations it was demonstrated that the emergence of membrane proteins might have been quite feasible. Specifically, the stability of monomers and dimers of a peptide built of leucine (L) and serine (S) amino acids in membrane-mimetic system was studied. The sequence of this peptide was $(LSLLLSL)_3$. Also the transmembrane aggregate of four identical a-

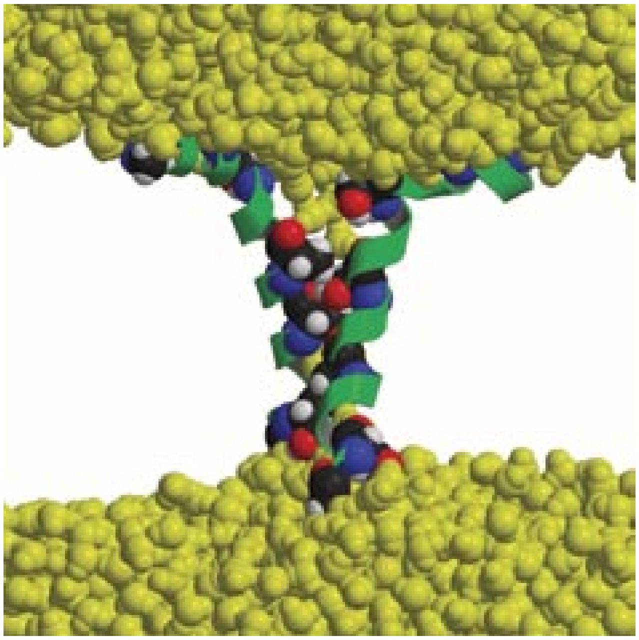


Figure – the (LSLLLSL)$_3$ peptide in the transmembrane orientation. The membrane-forming molecules located between two lamellae of water (in yellow) was removed for clarity.

helices that forms an efficient and selective voltage-gated proton channel was investigated. Finally, a peptide that forms sequence-specific dimers was studied.

Many peptides are attracted to water-membrane interfaces. Once at the interface, most nonpolar peptides spontaneously fold to (-helices. Whenever the sequence permits, peptides that contain both polar and nonpolar amino also adopt helical structures, in which polar and nonpolar amino acid side chains are immersed in water and membrane, respectively. The formation of such helices is primarily governed by the sequence of polar and nonpolar amino acids. Considering that specific identity of side chains is less important, the existence of helical peptides at interfaces of protocells should not have been rare.

Helical peptides located parallel to the interface could insert into the membrane and adopt a transmembrane conformation. However, insertion of a single helix is associated with a positive (unfavorable) free energy change. This is because polar groups in the peptide, which remain partially immersed in water at the interface, become completely dehydrated. However, the loss of free energy is smaller for helices than for other structures because polar groups in the peptide backbone are involved in intramolecular hydrogen bonding.

The unfavorable free energy of association can be regained by spontaneous association of peptides in the membrane. The first step in this process is the formation of dimers, although the most common structures involve aggregates of 4–7 helices. The helices could readily arrange themselves such that they formed pores capable of transporting ions and small molecules across membranes. Stability of transmembrane aggregates of simple proteins is often only marginal and, therefore, it can be regulated by environmental conditions, such as external electric fields, specific nature of membrane-forming molecules or small changes in the sequence of amino acids. This ability to respond to environmental signals might have led to the earliest, although quite imprecise, regulation of transmembrane functions.

A key step in the earliest evolution of membrane proteins was the emergence of selectivity for specific substrates. Many simple channels could achieve selectivity through placing one or only a few properly chosen amino acids in certain positions along the channel, which acted as filters or gates. From the evolutionary standpoint it is a convenient solution because it does not require imposing conditions on the whole sequence.

Many further steps were required before the simple aggregates of transmembrane peptides reached the structural and functional complexity, diversity and refinement of contemporary membrane proteins. The helices became connected by extra-membrane linkers to stabilize them inside the membrane. The resulting proteins aggregated to larger, higher-order structures. Protein sequences became optimized for highly specific functions. Finally, membrane proteins acquired large, water-soluble domains, which play regulatory role or help to supply energy for active transport. These evolutionary advancements opened the doors for the emergence of multicellular organisms.

CARBON NANOTUBE FIELD EMISSION X-RAY TUBE

Philippe Sarrazin, Lance Delzeit, David Blake

ARC is developing an X-ray tube for CheMin, a mineralogical instrument for planetary exploration. This instrument combines X-ray diffraction and X-ray fluorescence techniques to provide definitive mineralogical analyses onboard a lander or a rover. Space deployment of this instrument requires an X-ray tube that is miniature in size, low-power, and microfocused, meaning that the X-rays are generated from a very small spot (10–50 μm in size). Such an X-ray tube is not readily available.

An X-ray tube is composed of an electron-source facing a metallic target inside a vacuum enclosure. Electrons emitted by the source are accelerated towards the target by high-voltage. The collision of high-speed electrons with the target leads to the emission of X-ray radiation characteristic of the target material. The thermionic sources (hot filament) commonly used as electron sources (in conventional X-ray tubes) cause major problems for the deployment of a miniature X-ray tube in space: poor efficiency, heat generation, limited focusing capability. An alternative method for emitting electrons is field emission which is based on the extraction of electrons from sharp tips by an electric field. Field emitters can potentially improve efficiency, stability and reliability of miniature X-ray sources, however, until recently, no field emitter have shown the appropriate characteristics for X-ray tube application. Miniature microfocused x-ray tubes require very small emitters (10–100 μm in diameter) that are yet capable of delivering sustainable currents of about 100 μA. The work presented here is the development of a new type of electron-source for miniature X-ray tubes using field emission from carbon nanotubes (CNTs).

CNTs are the sharpest objects known, are very good conductors of electricity and are mechanically and chemically extremely robust. This combination of properties makes them very good candidates for field emission. CNT emitters were fabricated using thermal Chemical Vapor Deposition (CVD) techniques developed by Ames (figure 1). A major effort was dedicated to the adaptation of the CNT growth processes to different types of substrate materials. Electron emission properties of multiwall nanotube films of various densities were characterized using an instrument specifically developed for this project. Very good emission characteristics were measured with turn-on fields of 1.5 to 2 V μm^{-1}, and high current densities (figure 2). With optimized CNT density and very small emitters, outstanding sustainable current densities above 1 $A.cm^{-2}$ under moderate electric field (7–10 V μm^{-1}) have been measured. An industrial partner, Oxford XRT Inc., has implemented these cathodes in miniature X-ray tubes and is conducting performance tests. An X-ray tube is being submitted to a life-time test and has been oper-

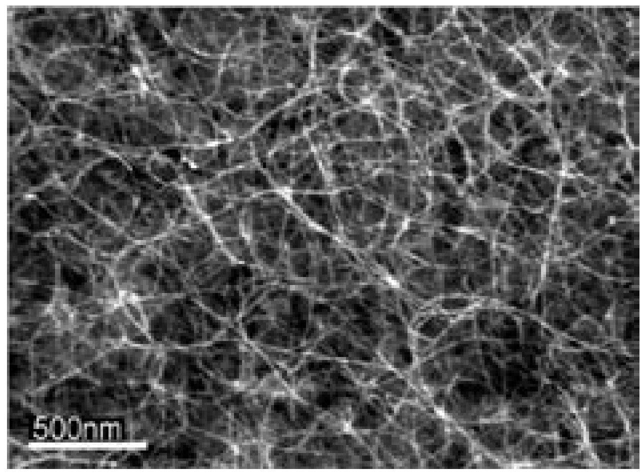


Figure 1: Carbon nanotube film obtained by thermal CVD.

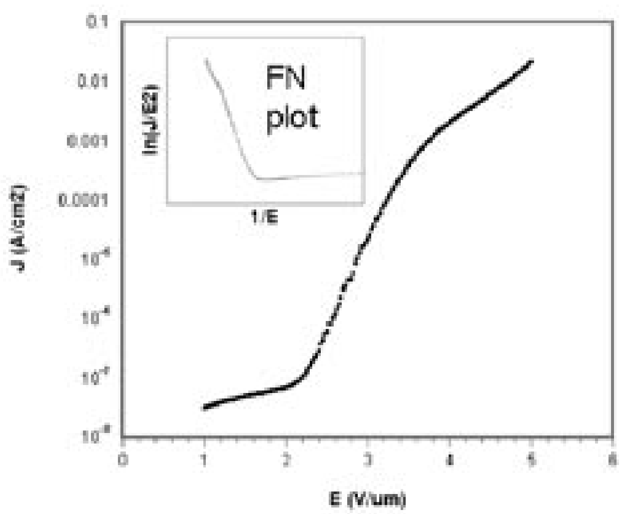


Figure 2: Example of field emission from a CNT film; main: applied electric field vs current density; insert: same data in a Fowler-Nordheim plot characteristic of field emission.

ated continuously for several months without any sign of deterioration. Current efforts are oriented towards the optimization of the emitter fabrication to produce even smaller electron-source with improved current density and stability.

Figure 3: CNT based miniature X-ray tube built by Oxford XRT Inc.

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